

Natural Resource Management and Policy  
*Ariel Dinar and David Zilberman, Series Editors*

# Impact of Pesticides on Farmer Health and the Rice Environment

edited by:  
Prabhu L. Pingali  
Pierre A. Roger

**IRRI**  
INTERNATIONAL RICE RESEARCH INSTITUTE

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# Impact of Pesticides on Farmer Health and the Rice Environment

# NATURAL RESOURCE MANAGEMENT AND POLICY

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## EDITORIAL STATEMENT

There is a growing awareness of the role that natural resources such as water, land, forests, and environmental amenities play in our lives. Society is challenged to manage competing uses for natural resources for improving social well being. Furthermore, there may be dire consequences for natural resources mismanagement. Renewable resources such as water, land, and the environment are linked, and decisions made about one may affect the others. Policy and management of natural resources now require an interdisciplinary approach including natural and social sciences to correctly address our society's preferences.

This series provides a collection of works containing the most recent findings on the economics, management, and policy of renewable biological resources such as water, land, crop protection, sustainable agriculture, technology, and environmental health. It incorporates modern thinking and techniques of economics and management. Books in this series will incorporate knowledge and models of natural phenomena with economics and managerial decision frameworks to assess alternative options for managing natural resources and environment.

This book addresses an important problem—the control of pests and the regulation of pesticides in rice, one of the world's major crops. The book embodies the essence of the series by taking an interdisciplinary approach, combining biological and public health models and information within an economic framework.

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# Impact of Pesticides on Farmer Health and the Rice Environment

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# 1 IMPACT OF PESTICIDES ON FARMER HEALTH AND THE RICE ENVIRONMENT: AN OVERVIEW OF RESULTS FROM A MULTIDISCIPLINARY STUDY IN THE PHILIPPINES<sup>1</sup>

P. L. Pingali

## 1.1. Introduction

Pesticides continue to be a significant and growing component of modern rice technology. The relative importance of pesticides has increased despite the availability of alternatives to exclusive chemical pest control such as varietal resistance and integrated pest management (IPM). While Asia's elite are becoming increasingly concerned about the adverse long-term effects of pesticides on the environment and human health, little scientific research has been done to address this issue. The few studies that exist are based on speculative and anecdotal paradigms. This chapter provides an overview of a multidisciplinary scientific effort to identify the incidence and magnitude of on-site and off-site environmental effects of pesticide use.

Indiscriminate pesticide use can result in one or more of the following: (1) health impairment due to direct or indirect exposure to hazardous chemicals; (2) contamination of ground and surface waters through runoff and seepage; (3) the transmittal of pesticide residues through the food chain to the farm family and urban consumers; (4) an increase in the resistance of pest populations to pesticides, thereby reducing their efficacy and consequently causing pest outbreaks; (5) the reduction of beneficial insects like parasites and predators, thereby

reducing the effectiveness of pest control strategies that attempt to minimize pesticide use; and (6) the reduction in the populations of microorganisms in the paddy soil and water that help sustain soil fertility while lowering chemical fertilizer use. The incidence and magnitude of each of these effects depend on the types of chemicals, frequency and quantities applied, and their persistence.

Where any of the above externalities are significant, the farmer's private costs of pesticide use are lower than the social costs of pesticide use. This would be so since farmer's private pest control decisions may not consider the damage to the environment and to health (due to a lack of information or otherwise). Knowing the incidence and magnitude of these social costs is important for identifying the true returns to promoting alternative strategies for pest control and for pesticide regulatory policy.

A multidisciplinary project was initiated in January 1989 to quantify all the private and social costs of pesticide use in Asian rice production. Biological, medical, and social scientists worked together on the same sample of farmers in three Philippine provinces—Laguna, Nueva Ecija, and Quezon—in order to provide a comprehensive assessment of the impact of pesticides on the lowland paddy ecosystem. Table 1.1 presents each of the effects examined and the disciplines involved. This chapter highlights the results of this project. Subsequent chapters provide a detailed discussion on methodologies and results for each component of the study.

The primary conclusion of this study is that the negative human health impact of pesticides is large and overwhelms their impact on the paddy ecosystem and the environment. In Asian rice systems, pesticide use is small in terms of dosages and number of applications, and the chemicals used degrade more rapidly in tropical flooded conditions than in the temperate upland conditions. While the chemicals used tend to degrade rapidly, they are, however, extremely toxic to humans, and exposure even at low levels tends to cause both acute and chronic health problems. Many pesticides commonly sold in Asia, extremely hazardous category I and II chemicals, are either banned or severely restricted for use in the developed world even when used with high levels of protection. In Asia, these chemicals are used with minimal protection, and the opportunities for increasing farmer safety are small. Pesticide regulation could help reduce the health costs borne by farmers by targeting the most hazardous and least productive pesticides. Finally, this study envisions high rates of return to research on nonchemical pest control methods, such as varietal resistance to pests that can be embodied in seeds, or the use of natural enemies and other biological controls.

Table 1.1. Description of the Project Objectives

| <i>Objective</i>             | <i>Disciplines</i>                                                                       | <i>Extensive Sampling</i>                                                                                         | <i>Intensive Sampling</i>                                       |
|------------------------------|------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|
| <i>On-paddy effects:</i>     |                                                                                          |                                                                                                                   |                                                                 |
| Rice plant                   | Pesticide toxicology                                                                     | Pesticide residue in rice grain                                                                                   | Pesticide residues in grain, straw, and stalks                  |
| Soil                         | Soil microbiology                                                                        | Microbial biomass<br>Blue-green algae (BGA)<br>Tubificid worms<br>Pesticide residue                               |                                                                 |
| Paddy water                  | Pesticide toxicology<br>Plant pathology<br>Zoology<br>Botany                             | Nematodes<br>Zooplanktons<br>BGA<br>Water quality<br>Pesticide residue                                            | Zooplanktons<br>BGA<br>Water quality<br>Pesticide residue       |
| Ground water                 | Pesticide toxicology<br>Entomology<br>Soil science<br>Entomology<br>Pesticide toxicology | Aquatic insects<br>Pesticide residue and movement of pesticides                                                   | Aquatic insects<br>Pesticide residue and movement of pesticides |
| Water run-off from the paddy | Botany                                                                                   | Water quality                                                                                                     | Water quality                                                   |
| Pest-predator complex        | Entomology<br>Plant pathology                                                            | Insect pests<br>Beneficial insects<br>Nematodes                                                                   |                                                                 |
| <i>Off-paddy effects:</i>    |                                                                                          |                                                                                                                   |                                                                 |
| Well water                   | Entomology<br>Pesticide toxicology                                                       | Pesticide residue                                                                                                 |                                                                 |
| Surface water                | Water engineering<br>Residue chemistry                                                   | Laguna de Bay<br>Water quality and transport of residue to surface water systems<br>Monitoring of fish population |                                                                 |

Table 1.1. (Continued)

| <i>Objective</i>                                                            | <i>Disciplines</i>                         | <i>Extensive Sampling</i>                                                                                                                                                                                                                                                                                                                                                        | <i>Intensive Sampling</i>   |
|-----------------------------------------------------------------------------|--------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| Vertebrate                                                                  | Vertebrate biology<br>Pesticide toxicology | Pesticide residue in fish, snails, frogs, shrimps, ducks, and chicken                                                                                                                                                                                                                                                                                                            |                             |
| <i>Farm household health:</i>                                               |                                            |                                                                                                                                                                                                                                                                                                                                                                                  |                             |
| Farmers, pesticide applicators                                              | Medicine                                   | Baseline health data: <ul style="list-style-type: none"><li>• Medical history</li><li>• Physical examination</li><li>• Laboratory tests (urine, stool, blood chemistry, chest X-ray, EKG, cholinesterase tests)</li></ul> Monitoring health data: <ul style="list-style-type: none"><li>• Physical examination</li><li>• Follow-up test</li><li>• Cholinesterase tests</li></ul> | Cholinesterase tests        |
| <i>Socio-economic effects:</i>                                              |                                            |                                                                                                                                                                                                                                                                                                                                                                                  |                             |
| Farmers, pesticide applicators, family members, and people in the community | Economics                                  | Survey on pesticide use, pesticide management practices                                                                                                                                                                                                                                                                                                                          | Monitoring of pesticide use |

### ***1.1.1. Methodologies for Farm Data Collection and for Sampling Environmental, Biological, and Health Effects***

This study deviates from the controlled experimental paradigm for measuring the effects of pesticide use. Environmental, biological, and health effects of pesticide use are measured by observing actual farmer behavior, monitoring farmers' health, and sampling farmer fields. There was no prior agreement with the farmers on the types or quantities of chemicals to use. Variability in pesticide use, and therefore variability in the effects of pesticides, was obtained primarily through a comparison of users and nonusers; and an examination of differences across the cross-section of farmers and across time. The results of this study indicate, however partially, the actual effects of pesticides on the environment and human health rather than simulated effects.

Three provinces in the Philippines participated in the study—namely, Laguna, Nueva Ecija, and Quezon. Environmental and biological data was collected from thirty-two, forty-two, and thirty-nine farm households in Laguna, Nueva Ecija, and Lucban, Quezon, respectively. The health study included a total of 152 individuals: the above 113 farmers plus 39 pesticide applicators (24 in Laguna, 15 in Nueva Ecija, and 0 in Quezon). Farmers in Laguna and Nueva Ecija practice intensive irrigated rice production and commonly used pesticides (see Chapter 3). While farmers in Quezon cultivate rainfed rice at lower cropping intensities than the other two areas, Quezon farmers do not use any insecticides or herbicides for rice cultivation. The Laguna sample was monitored during the 1989 dry and wet seasons (1989 DS, 1989 WS) and the 1990 dry season (1990 DS); Nueva Ecija sample, during the 1991 dry season (1991 DS); and Quezon, during the 1990 dry season (1990 DS). Prior data on production technologies, input use practices, and so on were available from the International Rice Research Institute (IRRI) Social Sciences Division, for part of the Laguna sample since 1966 and part of the Nueva Ecija sample since 1979.

**1.1.1.1. Monitoring On-Paddy Effects of Pesticides.** For the Laguna farms, rice plants, paddy soils, paddy water, ground water, and water runoff from the paddy were analyzed for the impact of pesticides. The analysis was multidisciplinary in nature, consisting of residue analysis of soil, paddy water, rice grain, and straw, and counts of biological parameters such as algae, microbial biomass, zooplanktons, pests, predators, and so on.

Two types of monitoring activities were conducted: extensive and intensive monitoring (Table 1.1). For the extensive monitoring, each of the thirty-two Laguna sample farms were visited one or more times per crop season and biological data were collected, in order to obtain samplewide information on the



parameters listed in Table 1.1. Intensive monitoring was conducted on two paddies for the biological variables, with the chosen paddies stratified by level of pesticide use as high and low. Intensive sampling of microflora and microfauna was conducted at zero, one, two, three, four, five, six, and seven days after every pesticide application while intensive sampling for soil, paddy water, and the rice plant was continued up to forty-five days after the last pesticide application. Intensive monitoring was conducted to understand the process by which the externality is created on the paddy ecosystem.

**1.1.1.2. Monitoring Off-Paddy Effects of Pesticides.** Pesticide runoff into the irrigation and drainage canals surrounding the paddy, and aquatic vertebrates in these waters, such as fish, snails, frogs, and shrimp, were extensively sampled for pesticide residues. Samples of well water from which the farmers get drinking water were also analyzed. The process by which pesticides are transported to the groundwater system was monitored on the intensively sampled fields.

**1.1.1.3. Farmer Health Monitoring.** All fifty-six Laguna respondents, fifty-seven Nueva Ecija respondents, and thirty-nine Quezon respondents were brought to the medical clinic at IRRI for a detailed baseline medical assessment.\* This included an interview, physical examination, a battery of laboratory tests and exposure history. A set of medical indices of pesticide exposure were defined and the exposed (Laguna and Nueva Ecija) and control (Quezon) groups were compared relative to these indices. Medical indices were related econometrically (using logit regressions) to a set of pesticide use indicators obtained from the farm monitoring survey. Probabilities of health risk were assessed relative to differential levels of pesticide use, differences in types of chemicals used and farmer characteristics, such as age, nutritional status, smoking and drinking habits. The impact of health impairments on the returns to pesticide use, and on labor productivity was likewise assessed.

**1.1.1.4. Monitoring Production Practices and Behavior.** Over the course of the study, sample farm households were intensively monitored for all input and technology use practices with special emphasis on pest management practices, including safety practices in pesticide handling and storage. Approximately four visits per crop season were made to each sample household. Detailed pesticide knowledge, attitudes, and practices surveys were conducted in Laguna and Nueva Ecija. At the latter site, a series of games were played with a larger set of farmers, including the study's sample farmers, to assess their knowledge of the efficacy and toxicity of various chemicals.

### 1.1.2. *Profile of Rice Pesticide Use*

Rice production accounts for about half the total insecticides, over 80 percent of the herbicides, and 4 percent of the fungicides sold in the Philippines (Chapter 3). Molluscicides have also been used in small quantities since 1987 to control the growing snail infestation. Relative to heavy users such as South Korea and Japan, the total amount of pesticides used in the Philippines is small. Rice agrochemicals accounted for only 2 percent of the world market value in 1988 (Woodburn, 1990). A detailed assessment of pesticide use on the sample farms, farmer perceptions, and knowledge about pesticides and safety practices is provided in Chapter 3.

The Laguna and Nueva Ecija farmers have been applying pesticides for over three decades. Most farmers make two to three applications of insecticides and one application of herbicides. The insecticides used are organophosphates, such as monocrotophos, organochlorines, such as endosulfan, and carbamates, such as BPMC. Of the thirty-seven chemicals used on the sample farms, only ten are registered for general use in the United States. The others are for restricted use or not used at all, which is especially true of the highly hazardous category I and II chemicals. Unsafe pesticide storage, handling, and disposal practices, documented in Chapter 3, subject the farmer to high levels of health hazards and contaminate the paddy ecosystem. Safe spray equipment and protective clothing, suitable for tropical conditions, are not available for Philippine rice farmers. Farmers also forage the rice paddies for food, such as fish and frogs, and feed, such as aquatic plants and rice straw, that could be contaminated by pesticides.

Farmers often lack accurate knowledge about pests and their control, hence underdosing and frequent applications are generally observed. Current pesticide pricing and regulatory structure plus inadequate storage, unsafe handling practices, short reentry intervals, and inefficient sprayer maintenance taken together provide an environment of greater accessibility or exposure to chemicals not only by the farmer applicator but by the farming household as well. Training and information campaigns on proper pesticide management could reduce the social costs of pesticide use, but these are too few in number and inadequate in content.

With the advent of rice varieties that are resistant to a wide variety of insect and disease pressures, the importance of pesticides for reducing yield variability has declined. Rola and Pingali (1993) have shown that the yield gains through insecticide application are modest when using resistant varieties, and that natural control or the “do nothing” option is the most profitable pest control strategy under normal circumstances. The release of resistant varieties, however, was not accompanied by supporting information campaigns on the reduced need for insecticides. Consequently, continued high and injudicious insecticide applications lead to the frequent breakdown in varietal resistance. Moreover, Heong

(1991) argues that indiscriminate pesticide use has lead to larger pest-related yield losses than not applying pesticides at all. The social consequences, on the environment and human health, of improper pesticide use and management are discussed below.

## **1.2. Results of Environmental and Biological Assessment**

In this section we attempt to provide a holistic and interpretative presentation of the disciplinary investigations on the biological and environmental impacts of pesticides. Details on how each scientist or team of scientists conducted their investigations can be found in the referenced chapters. Results are presented in two broad groups: on-paddy effects and off-paddy effects.

### **1.2.1. On-Paddy Effects of Pesticides**

**1.2.1.1. Pesticide Residues in the Paddy Soil, Rice Plant, and Grain.** Paddy soil, rice straw, and rice grains were checked for residues of the pesticides monitored on the farmers' fields (Chapter 6). An examination of rice straw and rice grain, both dehusked and rough grain, at harvest showed no detectable residues of pesticides for all seasons—1989 DS, 1989 WS, and 1990 DS. This could be expected because of the thirty- to forty-day interval between the last spray application and harvest. Moreover, the chemicals applied degrade rapidly within a tropical lowland environment (Tejada, Varca, and Magallona, 1977; Varca, 1981; Tejada and Magallona, 1986; NCPC, 1983). Residues detected on the rice grain in market basket studies done previously in the Philippines indicate that these have come from the use of pesticides during storage and not during field application (NCPC, 1981).

Soil samples were analyzed at the start of each season for pesticide residues from applications made in the previous season (Chapter 6). Residue analysis indicated that there was no buildup of pesticide residue in the soil. A similar result was obtained with repeated application of carbosulfan (Tejada, 1985) and endosulfan and lindane (Medina-Lucero, 1980). Tropical flooded rice soil is an ideal environment for the rapid detoxication of certain pesticides known to persist in nonflooded soils and other aerobic systems (Roger, 1989; Sethunathan and Siddaramappa, 1978). The rate of pesticide degradation increases with temperature, organic matter content, and soil pH (Ponnamperuma, 1972). Furthermore, Roger (1989) argues that repeated application of the same pesticide can enhance the growth of specific decomposing microorganisms and cause the rapid

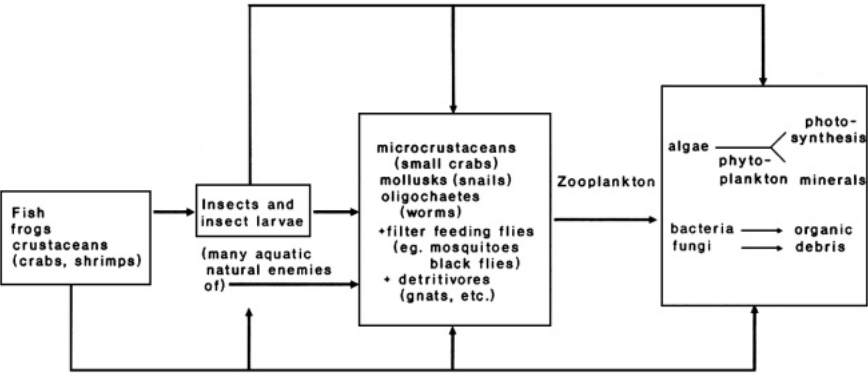


Figure 1.1. Stylized Food Chain: Flooded Paddy Systems

inactivation of the pesticide. A second application of gamma-BHC fifty-five days after the first application showed a faster rate of degradation (Raghu and MacRae, 1966). Diazinon persisted for about fifteen days in a flooded soil that had been previously treated with this insecticide but persisted for about sixty days in a soil that had never been exposed to diazinon (Sethunathan, 1972, as cited in Roger et al., 1987).

These results indicate that, for flooded rice, small amounts of pesticides applied at recommended rates and intervals do not persist beyond the crop growing period, either in the soil or on the plant and rice grains.

**1.2.1.2. Pesticide and the Food Chain.** Rice paddies are home to an intricate food chain composed of vertebrate and invertebrate organisms. Figure 1.1 provides a stylized representation of the organisms in the paddy system and their hierarchies. The dominant group of vertebrates are fish, frogs, and rats. The invertebrates, in turn, range from macro- to microorganisms: crustaceans (crabs, crayfish, and shrimp), microcrustaceans (these are best described as small crabs, ostracods, copepods, and cladocerans), aquatic insects and insect larvae, molluscs (snails), annelids (worms), microflora (algae), and microfauna (bacteria). Maintaining a balance among these groups of organisms is essential both for human nutrition and for sustaining soil fertility. The rural poor across Asia forage rice paddies for fish, shrimp, and other organisms to augment their protein supplies (Chapter 3). Nutrient recycling in the paddy soils occurs essentially through interdependencies of the micro and macro organisms in the paddy soil and water complex (Chapters 9, 10, and 11).

How does the use of pesticides affect the food chain? Pesticide use could lead to a reduction in species number, changes in species composition, and an

accumulation of residues in the surviving populations. The existing evidence from the literature and from this project's field monitoring activities are presented here.

*Impact on Vertebrates.* Much of what we know about the impact of pesticides on the paddy vertebrates comes from laboratory or controlled experiments (see, for example, Bajet and Magallona, 1982; NCPC, 1983; Tejada, 1985; and Tejada and Magallona, 1986). The following conclusions can be reached from the existing literature: (1) the absolute number of aquatic vertebrate declines rapidly with pesticide use, with mortality usually occurring within the first five to seven days after pesticide application; and (2) for the surviving populations, the level of detectable residues was generally small. Results of residue analysis from aquatic vertebrates collected as part of this project are provided later in the chapter under off-paddy effects.

A rice-fish farming system, a traditional practice in low-intensity systems, is being promoted in the irrigated lowlands of Asia as an alternative to rice monoculture in order to increase protein supplies for farm households. Since fish must generally adapt to management practices for rice, information on the toxicity, degradation, and residues of pesticides in fish is necessary for a better symbiotic relationship between rice and fish in an integrated system. Such a study was conducted by Cagauan (Chapter 8) under experimental and field conditions. Results showed that toxicity of insecticides to fish ranged from extreme to moderate. There were no insecticides observed with low toxicity. Toxicity of herbicides tested was generally moderate to low. Molluscicides, especially organotin compounds, are highly toxic to fish in a rice-fish system.

Field toxicity trials showed that insecticide application at least seven days before fish stocking ensured high fish survival but not subsequent applications after fish stocking. In some tests, fish stocking before any insecticide application was not adversely affected in lower rates of synthetic pyrethroids although residues were found in the water.

*Effects on Invertebrates.* Existing evidence indicates that insecticide applications have relatively small effects on invertebrate populations, especially crabs and snails. This is due primarily to the reduction in predator populations, such as those of fish and frogs. Simpson and Roger (Chapter 9), on the other hand, report that insecticides and herbicides have a detrimental impact on tubificid worm populations. Tubificids are an important source of food for fish; they also contribute to maintaining soil fertility by mixing and aerating the soil. A pesticide regime consisting of carbofuran, butachlor, and triphenyl tin hydroxide, applied at recommended rates, reduced tubificid populations over the cropping season from 1,800 per square meter to less than 200 per square meter (Chapter 11).

*Effects on Soil and Aquatic Microflora.* Aquatic and soil microflora, such as algae, are important components of the food chain and contribute to soil fertility maintenance through nitrogen fixation. They serve as food of higher-order vertebrates such as fish and frogs. Tejada et al. (Chapter 6) and Roger et al. (Chapter 11) tried to establish the effect of pesticide use on the population of microflora found within the paddy field.

Most of the early information on the effects of pesticides on nontarget microorganisms comes from observations in temperate upland soils. However, during the last two decades, information on tropical wetland soils has become available (Roger, 1990). Chapter 10 provides an exhaustive review of this literature. Of the 120 studies reviewed, only twelve of them were field experiments, while the rest were experiments performed in the laboratory. A synthesis of existing evidence indicates that insecticides applied over the long term could be detrimental to algal populations by decreasing species diversity and causing a rapid recruitment of ostracods (small crabs, 1–2 mm long). The latter, being more tolerant to insecticides, increase in large numbers, particularly as the natural predators succumb first. Therefore, while algal blooms are observed during the initial days after pesticide application, they tend to disappear soon after because of increased population of grazers.

Insecticides followed by herbicides are the most important pesticides that adversely affect microflora populations in a ricefield ecosystem. Among the insecticides, carbamates had the most detrimental effects, followed by organochlorines and organophosphates (Chapter 6).

**1.2.1.3. Pesticides and the Long-Term Fertility of Paddy Soils.** Research on nitrogen uptake by the rice plant has shown that most of the nitrogen absorbed by the plant originates from the soil. Only a small fraction of the nitrogen in the soil is available to the plant, and most of this available nitrogen originates from the soil's microbial biomass (Watanabe, De Datta, and Roger, 1988). Crop residues, algae, aquatic plants, tubificid worms, and other soil organisms contribute to the replenishment of microbial biomass. There is a concern that enhanced pesticide use might alter the soil microflora and microfauna responsible for maintaining soil fertility. A synthesis of the existing literature and field research provides an understanding of the effects of pesticide use on (1) the productivity of the microbial biomass and (2) the populations of soil and water invertebrates responsible for nutrient recycling (see Roger et al., Chapter 11; Simpson and Roger, Chapter 9; and Tejada et al., Chapter 6, for details).

Field and laboratory studies with paddy soil show that pesticides applied at recommended levels rarely had detrimental effects on microbial populations or on their activities (Roger, Chapter 10). When significant changes in microflora were observed during tests lasting several weeks, a recovery of populations was

observed after one to three weeks. On the other hand, invertebrate populations, especially tubificid worms, seem to be more sensitive to pesticides than the microflora. This negative effect indicates that pesticide use may reduce the translocation into deeper soil layers of recycled nutrients accumulating at the soil surface, thus reducing their availability to the rice plant.

For microflora, pesticides may have only a temporary effect but could lead to the disappearance or depression of components of the microbial community when applied repeatedly. This thus leads to a new equilibrium and changes in the pattern of microbial decomposition that might be detrimental. Substantial further work is required before any significant trends on the impact of long-term pesticide use on soil fertility are discerned.

**1.2.1.4. Effects of Pesticides on Pest and Predator Populations.** The impact of pesticides on pest populations is quite well understood for the Philippines (see Litsinger et al., 1987 for a survey of the literature and evidence). The impact of pesticides on predator populations is less well understood but is the subject of current inquiry at IRRI. The impact of pesticides on predator populations has substantial implications for pest control strategies that attempt to minimize pesticide use, such as integrated pest management. Applying pesticides routinely—early in the crop season or on schedule during the growing season (prophylactic application)—disrupts the pest-predator balance. Heong (1991) has shown that the predominant reliance on chemical control often leads to pest resurgence and frequent large-scale infestations. The virulent brown plant hopper (BPH) resurgence, for example, was highly influenced by the number of insecticide applications, their timing, and the kind of insecticides used. In this instance, the insecticides decimated the BPH-natural enemy population (Heong, 1991).

## **1.2.2. Off-Paddy Effects**

The off-paddy effects considered here are (1) pesticide residues in aquatic vertebrate populations (bioaccumulation), (2) pesticide runoff in the drainage water from the paddy into drainage canals and thereby into surface water systems, and (3) pesticide leaching into the groundwater and the pollution of drinking water.

**1.2.2.1. Pesticide Residues in Aquatic Vertebrates.** Tejada et al. (Chapter 6) examined vertebrates collected from drainage canals around the sample rice paddies in Laguna for possible pesticide residues. For both the wet and dry seasons of 1989–1990, fish, frogs, and shrimp were collected during the early crop period. At prebooting stage (forty-five days after transplanting), the paddy had been exposed to one herbicide application and at least one insecticide

application. In the wet season, all extracts of fish (tilapia, hito, mudfish) and freshwater shrimp revealed the possible presence of isoprocarb. The presence of isoprocarb could be attributed to its being less soluble in water; it could therefore be easily absorbed through gill membranes, facilitated by the countercurrent flow mechanism, before the toxicant is degraded in flooded paddies. Frogs collected in the same canal exhibited almost similar patterns of activity as those found on fish and shrimp. These chemicals are relatively less toxic to aquatic vertebrates, and therefore survivors are found in contaminated water.

Cagauan (Chapter 8) provides a detailed assessment of bioaccumulation in fish of common rice pesticides used at recommended doses. Fish that survive the first week of insecticide application rarely contained pesticide residues, if recommended rates of organophosphates, carbamates, and synthetic pyrethroids are used. Organochlorine compounds can accumulate in fish because they are relatively more persistent. The impact on fish of pesticides currently recommended for rice is their direct toxicity leading to high mortality rather than their bioaccumulation in harvested fish. Pesticide bioaccumulation in harvestable and edible size fish would be observed only in cases where repeated applications of low toxic but persistent chemicals are made.

**1.2.2.2. Pesticide Runoff from the Paddy.** Bhuiyan and Castañeda measured pesticide runoff from the paddy in Laguna (Chapter 7). A contiguous and hydrologically bound rice area of around 500 hectares within the Sta. Cruz Irrigation System (SCRIS), Laguna was delineated for the study. Water sampling stations were established within the study area at irrigation water inflow points and at the drainage water outflow points, to detect if any pesticide contamination occurred from the ricefields.

For water inflow into the paddy, residues of commonly applied insecticides and herbicides in the area were also detected. Pesticide residue values ranged from 0.01 to 0.54 ppb, which are within the range of 0.000001 to 0.1 ppm considered normal in natural surface waters. Residue concentrations in the drainage water outflow from the paddy was substantially higher at 0.001 to 3.46 ppb. The higher residue concentrations in drainage water are attributed to the pesticides carried by runoff water from treated areas. Pesticide residues were found to be higher in the wet season rather than in the dry season because of higher rainfall levels. Drainage canals in the area feed into Laguna Lake. From this study it is not possible to predict how much of the pesticides in the drainage water would naturally degrade in the process of transport to the lake and how long they persist in the lake.

**1.2.2.3. Pesticide Residues in Well Water and the Transportation of Pesticides Through the Soil to the Water Table.** Well water is used as drinking water by most of our farmer cooperators in Laguna and Nueva Ecija. Bhuiyan



and Castañeda analyzed pesticide residues in well water (Chapter 7). Thirty-two wells in Nueva Ecija and fourteen wells in Laguna were randomly selected for monitoring pesticide residues. Most of the selected wells were situated near the rice paddies ranging from 6 to 200 meters and depth ranging from 30 to 60 feet. Water sampling was done once a month for two consecutive cropping seasons during 1989–1991. Tejada et al. (Chapter 6) also analyzed residues in well water in the Laguna farms.

Water samples analyzed for the chemicals applied on farmers' fields showed seasonal concentrations of these chemicals that exceed maximum acceptable daily intake (ADI) levels. Both insecticides and herbicides commonly applied by farmers in the area were detected in the groundwater. Residue analysis also detected chemicals that were not even used on the farmers' fields. Residues of these latter chemicals such as DDT, endrin, and lindane were detected in both Laguna and Nueva Ecija. A small but significant amount of pesticides leaching into the groundwater was also detected.

The process by which pesticides are being transported from the paddy to the groundwater systems was examined through intensive sampling of a high endosulfan user in Calauan and of an average monocrotophos user in Calamba, both in Laguna (see Tejada et al., Chapter 6, for details on how this work was conducted). Results indicate that these chemicals degrade rapidly (within two weeks) in the paddy water and in the top soil, up to 25 cm depth, due to active microbiological and chemical degradation processes. However, significant amounts of these chemicals were found beyond the soil surface, at the 25 to 125 cm depth, up to five weeks after spraying. Small but detectable amounts of the chemicals were found at 175 cm soil depth even at seventy-three days after chemical application. These results indicate the possible threat of shallow groundwater contamination from the intensive use of insecticides and herbicides.

### *1.2.3. Results of the Health Assessment*

Medical comparisons of the samples exposed to pesticides with the unexposed samples revealed that the exposed groups face significantly higher acute and chronic health effects that can be attributed to prolonged pesticide use (Chapter 12). Eye, skin, pulmonary, and neurologic problems are significantly associated with long-term pesticide exposure. Pesticides that might be linked with these impairments include certain organophosphates, organochlorines, organotins, and phenoxy herbicides. Farmers using the highly hazardous category I and II chemicals are more susceptible to pesticide-related ailments than farmers using the relatively less hazardous category III and IV chemicals.

Farmers exposed to pesticides over the long term may face several of the

above illnesses at the same time. Pesticides may also cause other nonspecific illnesses in addition to those mentioned above. Seventy-nine percent of those in the Laguna sample and 80 percent of those in the Nueva Ecija sample had three impairments or more. Pesticide use has a significant positive association with the incidence of multiple health impairments, even after accounting for the effect of age, nutritional status, smoking, and drinking history of the sample farmers (Chapter 12).

The costs faced by farmers due to health impairments was computed based on the medical tests conducted (Chapter 12). Treatment costs (including medication and physicians' fees) plus the opportunity cost of farmers' time lost in recuperation formed a measure of the health cost per farmer. The average health cost for farmers exposed to pesticides was approximately 40 percent higher than that for the unexposed farmers. Even after accounting for age, nutritional status, smoking, and drinking, health costs increase by 0.5 percent for every 1 percent increase in insecticide dose above the average level. In addition to the direct health costs, the loss in labor productivity associated with impaired health is quantified in Chapter 13.

#### 1.2.4. *Economic Synthesis*

Antle and Capalbo provide a comprehensive benefit-cost framework that explicitly accounts for pesticide externalities in the choice of pest control technology (Chapter 2). Such a framework is essential as an input into making informed policy decisions on pesticide use and as input into addressing more encompassing issues such as long-run sustainability of intensive rice production systems with high levels of pesticide use. The framework itself allows for the modeling and valuation of all environmental and health externalities associated with pesticide use. However, in this study, while documentation of the presence of most externalities has been possible, quantification and valuation could be done only in the case of health effects. A thorough benefit-cost analysis was therefore done only for the health effects of pesticides (Chapters 12 and 13).

When health costs are explicitly considered, the net benefits of insecticides applied are negative (Chapter 12). In other words, the positive production benefits of applying insecticides are overwhelmed by the increased health costs. The value of crops lost to pests is invariably lower than the cost of treating pesticide-related illness and the associated loss in farmer productivity (Chapters 12 and 13). When health costs are factored in, the natural control ("do nothing") option is the most profitable pest management strategy. This result holds even when farmer aversion to the risk of crop failure is considered.

Simulation analyses presented in Chapter 13 show that there are likely to be

social gains from reducing insecticide use in Philippine rice production. This is estimated to have a small net effect on productivity because the loss from reduced pest control is largely offset by the gain from improved farmer health. Therefore, policies that reduce insecticide use in Philippine rice production would be likely to generate an improvement in social welfare through an improvement in farmer health.

The actual benefits of reduced pesticide use are likely to be greater than those estimated in this study for several reasons. The measure of health impairment may not account for the full social cost of illness, as it does not include the value of foregone leisure or reduced life expectancy and may understate the true opportunity cost of treatment and recuperation. Additional impacts on family members not directly involved in production, through incidental exposure and accidental poisonings, also have not been measured. Moreover, the on-farm and off-farm environmental impacts of agricultural pesticides, such as water contamination, have not been quantified in monetary terms. Taking these additional possibilities into account would only strengthen the case against pesticides.

### **1.3. Conclusions**

Results presented in this book indicate that for flooded rice, pesticides applied at recommended rates and intervals do not persist beyond the crop growing period, either in soil, in paddy water, or on the plant and rice grains. The problem, however, is that during the short period that they persist in the paddy environment they can have adverse effects on aquatic vertebrate and invertebrate organisms and on farm labor that enters the field to conduct other agricultural operations.

For aquatic vertebrates, the absolute numbers decline rapidly with pesticide use, although the level of detectable residues in the surviving populations is generally small. The important point here is that pesticide-using farmers trade off a higher quantity of protein supply from the paddy for a perceived increase in rice output. Deliberate interventions to increase protein supply from the paddy, through rice-fish farming for instance, would only be successful with advances in pest management technology that minimizes the above tradeoff.

With respect to soil and aquatic microflora and fauna, existing evidence seems to indicate that pesticides have only a temporary and transient effect. Long-term field experiments are needed, however, to establish conclusively the impact of pesticides on the ecology of floodwater and surface soil, especially with respect to the microbial biomass that helps sustain soil fertility.

Long-term indiscriminate pesticide use could have a negative impact on pesticide productivity because of its effect on nontarget organisms. Early season

prophylactic pesticide applications are known to have a greater impact on predator rather pest populations. This disruption in ecological balance leads to a surge in midseason pest populations. Similarly, if the same pesticides are applied over a period of time, there is a blooming of microorganisms that helps degrade the chemicals and thereby reduce its efficacy.

Our results indicate significant negative externalities of pesticides on the off-paddy environment. The ability of rural households, particularly the rural poor, to forage for protein food is limited by the extent that pesticides contaminate the canals surrounding the paddy and affect the quantity and quality of aquatic vertebrates. Similarly, seasonal groundwater contamination could have a significant impact on farm household as well as on other rural household health.

The findings of this study establish, for the case of irrigated rice in the Philippines, a consistent pattern showing that pesticide use has an adverse impact on human health and that impairment of health reduces farmer productivity. Eye, skin, pulmonary, and neurologic problems are significantly associated with long-term pesticide exposure. The majority of the pesticides that might be linked to these impairments (the highly hazardous category I and II chemicals) are commonly available in the Philippines but are banned or severely restricted in the developed world.

Taxes on pesticides can be used to reduce farmers' health risks and environmental externalities. For instance, if governments tax the highly toxic category I and II chemicals heavily enough, farmers may switch to the less hazardous category III and IV chemicals. More discretion should also be used in importing and licensing agrochemicals. Judicious pest management is possible only when policymakers and farmers discriminate in their choice of pest control methods and chemicals.

The rate of return to research and training that reduces pesticide use may be underestimated when health and environmental effects are not factored in. For example, if IPM technology lead to the reduction of pesticide use, any associated improvements in health or environmental quality should be counted as benefits from the adoption of IPM. The estimated rate of return to IPM research would be commensurately higher.

## Notes

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2. The medical assessment was carried out by a medical team consisting of a physician, nurse, X-ray technician, and medical technologist. The nurse interviewed the farmers regarding their personal, family, and occupational histories, including drinking and smoking habits. The doctor performed a

complete physical examination on all the farmers using a protocol especially designed for the project. Cholinesterase determinations were done by the medical technologist, while chest X-ray and electrocardiogram (EKG) were done by the X-ray technician. The readings for the EKG and the X-ray were done by two cardiologists and a radiologist, respectively.

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# 2 MEASUREMENT AND EVALUATION OF THE IMPACTS OF AGRICULTURAL CHEMICAL USE: A FRAMEWORK FOR ANALYSIS

J.M. Antle and S.M. Capalbo

## 2.1. Introduction

Agricultural productivity has increased substantially in the last half century due in part to the introduction and expanded use of agricultural chemicals. More recently, however, some agricultural practices including those associated with pesticide and fertilizer use have been viewed as having a major impact on the ecosystem and as being sources of environmental pollution and human health problems. Concern with the potential linkages among human health, environmental quality, and agricultural productivity reflects the growing demand by the general public and the international donor community for researchers to recognize the social benefits and social costs of agricultural technology and to address the long-run sustainability of existing agricultural practices.

The environmental and health impacts have often been omitted in analyses of returns to agricultural research or in evaluation of specific agricultural policies or programs because of the lack of an appropriate methodology and because of data deficiencies. No comprehensive methodology or analytical framework has been developed that combines field-level relationships among management practices, environmental attributes of the farmland, and nonpoint pollution with impacts on human health, despite substantial disciplinary research in physical,



biological, economic, and health sciences. The research from these various disciplines needs to be integrated into a framework that, to be useful for policy analysis, makes the link between the physical changes in environmental and resource quality attributable to agricultural practices and the valuation attached to those changes in environmental quality and human health. The data deficiency concerns are twofold: (1) the information needed to quantify the environmental quality and agricultural production relationships has generally not been available; and (2) the data on human health effects of exposure to agricultural chemicals are incomplete.

This paper addresses the methodological deficiencies by developing an approach to integrating disciplinary research to quantify and value the impacts of agricultural chemical use. The basic premise of this paper is that economics provides a framework to integrate the disciplinary models and data for policy analysis. Thus, economists must play a central role in the organization and interpretation of the physical, biological, health, and social science research that is needed to quantify and value the impacts of agricultural use.

The framework developed in this paper is useful to address the impacts of specific changes in public policy, such as pesticide restrictions, and to address more aggregate issues such as agricultural sustainability and dynamic measure of productivity. The paper is organized as follows: Section 2.2 is a discussion of the conceptual framework for evaluating the net social benefits of chemical use. In this section, we argue that modern benefit-cost analysis provides the conceptual framework to organize a coherent approach to the problem of incorporating environmental and health impacts into public policy analysis and for addressing the uncertainties inherent in this type of analysis. Section 2.3 discusses some of the physical models that can be used to predict the movement of pesticides in the soils; Section 2.4 deals with modeling health effects. In Section 2.5, attention is focused on economic production models. Selected methods for valuation of market and nonmarket effects of agricultural production practices are discussed in Section 2.6. Section 2.7 contains a discussion of issues that arise in integrating disciplinary models for addressing sustainability concerns, human health impacts, and impacts on the environment. Section 2.8 concludes the paper with a summary of the research needs and a discussion of how this approach is useful in addressing concerns regarding agricultural sustainability.

## **2.2. Conceptual Framework**

### **2.2.1. *Benefit-Cost Analysis***

Benefit-cost analysis (BCA) provides the foundation for developing the framework for valuing chemical externalities. BCA is a systematic, quantitative method

for the comparative evaluation of alternative activities in areas such as public expenditures, regulatory activities, or production practices. Its goal is to identify the alternative that will make the most efficient use of society's scarce resources in promoting social objectives—that is, providing maximum net social benefits. The requirements that benefits exceed costs before a regulation, expenditure, or production practice is deemed socially desirable translates into a requirement that the value that society attaches to what is obtained from that specific use of the resource must exceed the value to society of the resource in an alternative use. The benefits and costs “may take many different forms, occur at different times, involve different degrees of uncertainty, and affect different individuals. The economic theory of benefit-cost analysis provides a framework for taking such diversity into account” (Halvorsen and Ruby, 1981, p. 1).

BCA has been a controversial aspect of government decision making in the United States since its inception as a criterion for decision making in the Flood Control Act of 1936. In the mid-1960s, BCA was viewed as an objective means for expanding government spending while reducing the influence of special interests so that government programs could be more effective in aiding those that they were intended to aid (Campen, 1986). In 1981, under Executive Order 12291, BCA became a central element in regulatory policy and, for the first time, played an integral role in U.S. environmental policy making (Smith, 1984). Executive Order 12291 stipulated that “regulatory action shall not be undertaken unless the potential benefits to society from the regulation outweigh the costs to society,” that economic efficiency should be the basis for evaluating all new major regulations or revisions, and that the criterion for selecting among alternative regulations be consistent with maximizing the aggregate net benefits.

The use of BCA to assess the merits of environmental regulations, including regulations dealing with use of agricultural chemicals, has met with controversy due primarily to the presence of uncertainty and nonmarket effects. A large degree of uncertainty is present in quantifying the physical impacts, such as the chemical concentration reaching the groundwater, and in attaching values to these changes in the environment. The existence of uncertainty in all the disciplinary dimensions is all the more reason for collaboration among scientists to better understand the economic, physical, and health linkages.

Our promotion of the BCA paradigm as the foundation for a systematic evaluation framework for assessing the social impacts of chemical use is justified by the need to identify the relevant issues required to make judgments about the valuation of the physical interactions between production techniques and of the environmental and human health impacts. It is recognized that there will be factors that cannot be effectively incorporated into BCA, but “this underscores the importance of benefit-cost analysts’ systematically providing information about consequences of alternatives that cannot be readily evaluated quantitatively. Ultimately, choices are up to the decision makers, but BCA should offer

them as much help as it can . . . describing the limitations of the results obtained through BCA is an important part” (Campen, 1986).

### 2.2.2. *Components of a BCA Framework for Pesticide Use*

An ex ante BCA of a pesticide regulatory policy or technology requires prediction of the direct and indirect effects, expression of the effects in terms of common units, and a determination of the net impact on social welfare. The BCA process can be presented as a sequence of steps as shown in Figure 2.1. The first step, denoted by box 1, is to determine the effect of the policy or the change in technology on the output and input decisions of the farmers who utilize the pesticide in their production practices.

The second step is to quantify how a farmer’s response affects the magnitude of the benefits and costs. In the case of a reduction in chemical use, the benefits include reductions in the amount of toxics transferred into the environment and amount left on food as residues, and reduced levels of occupational exposure (see boxes 2a, 2b, and 2c). The costs include the impacts on production or yields (box 3).

The environmental impacts of changes in chemical use depend on the physical processes of chemical transport through soil and water mediums (box 4) and subsequent contamination of secondary food sources. These processes include chemical degradation, sorption by mineral and organic constituents in the soil, plant uptake of chemical materials, volatilization, and the effects of water flow processes that disperse and distribute the chemicals during passage through the unsaturated soil zones. These physical processes are discussed in Wagenet and Rao (1990); alternative models for analyzing chemical fate in the soil are discussed in Section 2.3.

Analysis of the effects of changes in chemical use on human health involves both human and environmental risk assessment (see boxes 5 and 6). Estimation of human health effects as a function of levels of exposure to pesticides, fertilizers, and other toxic substances is referred to as *health risk assessment*, and estimation of impacts on other species is called *environmental risk assessment*. A discussion of risk assessment as it relates to pesticide use is discussed in Section 2.4.

The third step in the BCA process is to express the benefits and costs in a common unit that reflects the valuation by the affected individuals (box 7). These values are commonly translated into monetary units. In order to value the costs of the chemical use restrictions, information on changes in production levels, production costs, and market are required, as well as estimates of the potential adverse impacts on consumers caused by changes in food production and prices. The values attached to resource uses are based on consumer

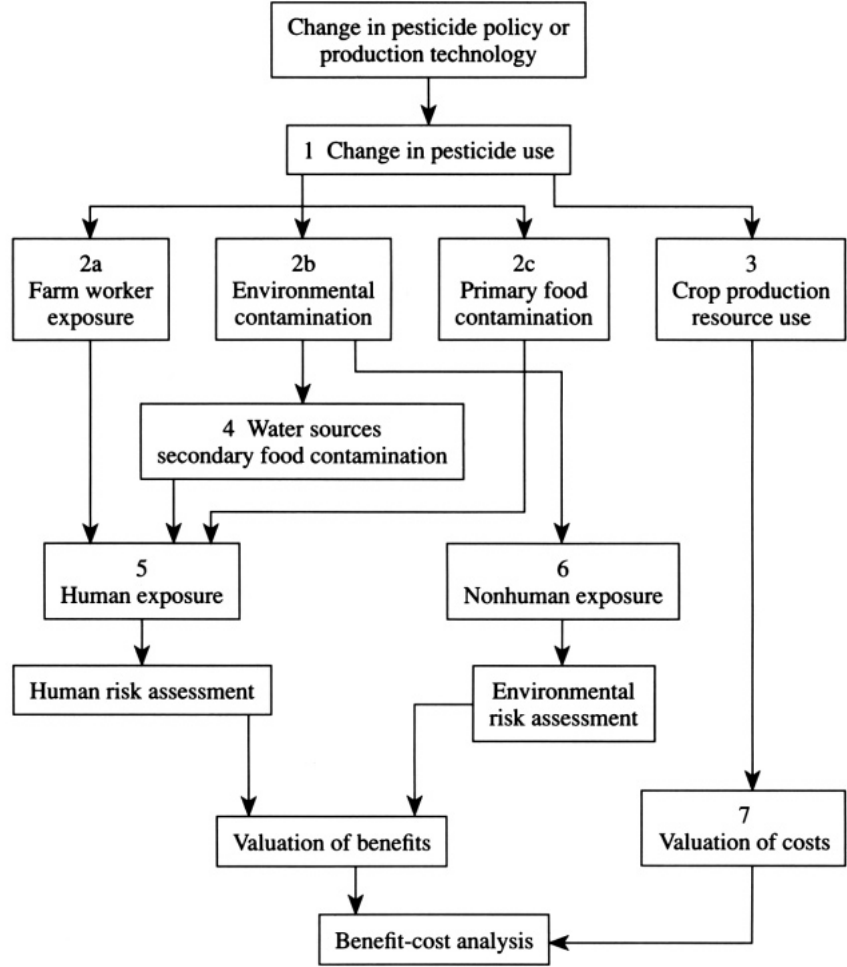


Figure 2.1. Major Components of a Benefit-Cost Analysis of a Change in Pesticide Use

sovereignty; individuals are felt to be the best judges of the values of the goods and services that they want, and these values are conditional on a given distribution of income. This approach assumes that in the absence of externalities, market prices reflect the individual's willingness to pay for the last unit consumed. When dealing with goods for which markets are either nonexistent or incomplete, nonmarket valuation techniques are required.

The final step in the BCA process is the determination of the net impact on

social welfare. This step requires a criterion for determining what qualifies as an increase in welfare and a means for aggregating the impacts that may occur at different points in time. The present discounted value of net benefits is often used as the criterion for evaluating the change in social welfare.

Net benefits are simply the difference between benefits and costs; whenever net benefits are positive, the policy or regulation results in a (welfare) gain to society. However, one of the most basic problems in benefit-cost analysis, and in addressing the impacts of regulations, is that costs are accrued or benefits are created at different points in time and that individuals discount the future. Benefits and costs realized in different times can be converted to their present value by a process known as discounting and then compared. The present discounted value of a stream of benefits and costs that occur in different time periods is

$$\sum_{t=0}^T (B_t - C_t)/(1+r)^t,$$

where  $B_t$  and  $C_t$  represent the gross benefits and costs in each period,  $r$  is the discount rate, and  $t = 0, \dots, T$  is the time horizon for the benefits and costs.

In summary, to account for the social costs or externalities associated with the use of agricultural chemicals—or conversely, to determine the net benefits of a change in chemical use—it is necessary to first quantify the relationship between agricultural production and chemical use; second, to measure and value the subsequent impacts on environmental quality and human health; and third, to make a determination as to whether society is a net gainer or loser as a result of this regulation, policy, or technology.

### 2.2.3. *A Mathematical Formulation*

To illustrate how the benefit-cost framework translates into a quantitative model, consider the following formulation of the net benefits of a policy that regulates the amount of the pesticide  $j$  that can be applied:

$$E(NB_i) = E(B_i) - E(C_i), \quad (2.1)$$

where  $E(B_i)$  denotes the expected benefits of policy  $i$  and  $E(C_i)$  denotes the expected costs associated with implementing this policy. The expected costs of this policy would reflect the losses in net returns to farmers as a result of the limitations on pesticide  $j$  and the loss in consumer surplus that may occur as a result of the higher prices for the products for which pesticide  $j$  is an input. If enforcement and monitoring activities are required, these would also be included as a cost.

The expected benefits of the policy that restricts pesticide use are measured

by comparing the existing degree of ground and surface water pollution and health risks from pesticide use with the reduced levels of pollution and health risks that would result from lower pesticide usage.

Some of the recent attempts to measure the benefits of groundwater protection policies designed to control hazardous wastes have utilized the change in expected damages to approximate the benefits of a groundwater protection policy (see Raucher, 1983).<sup>1</sup> The benefits of tighter regulations (or bans) on pesticide use would reflect the value placed on the change in the amount of pesticide residue on foods and other vegetation as well as the value placed on the cleaner environmental mediums, such as groundwater and surface water, and the resulting positive impacts on human health from reduced occupational exposure.

Consider the following specification of the expected benefits of a policy that restricts the use of pesticide  $j$ :

$$E(B_j) = -dE(D_j)/dx_j = -d\{m(x_j) \{qC_s + (1 - q)C_h\}\}/dx_j, \quad (2.2)$$

where  $D_j$  denotes damages,  $x_j$  denotes the pesticide use level,  $m(x_j)$  denotes the damage function that translates changes in surface applications of  $x_j$  into changes in the amount reaching the groundwater,  $dm/dx > 0$ ,  $q$  denotes the probability that contamination would be detected,  $C_s$  denotes the cost of response to known contamination ( $C_s$  is a function of  $m$ ), and  $C_h$  denotes the health cost incurred if contaminated water were used ( $C_h$  is an increasing function of the level of pollution and population).

The right side of equation (2.2) is the expected per unit cost of the pesticide pollution times the amount that shows up in the groundwater aquifer. The change in this expected cost of pollution then provides an estimate of the damages avoided as a result of this policy. This specification reflects only a subset of the possible user benefits. A complete specification of benefits would also need to reflect the user benefits associated with reduced food residue consumption and reduced occupational exposure.

Equation (2.2) is useful in illustrating the integration of the physical models of pesticide transport,  $m(x_j)$ , with the economic information on valuation. In subsequent sections we examine a simple transport model for assessing the environmental damage relationships that could be used in a BCA and discuss in greater detail the valuation issues and model integration.

### 2.3. Physical Models for Quantifying the Contamination Levels

Physical models for quantifying pesticide or chemical pollution externalities need to address movement of pesticides to both surface and ground water. In the last three decades an extensive literature has been generated by research aiming

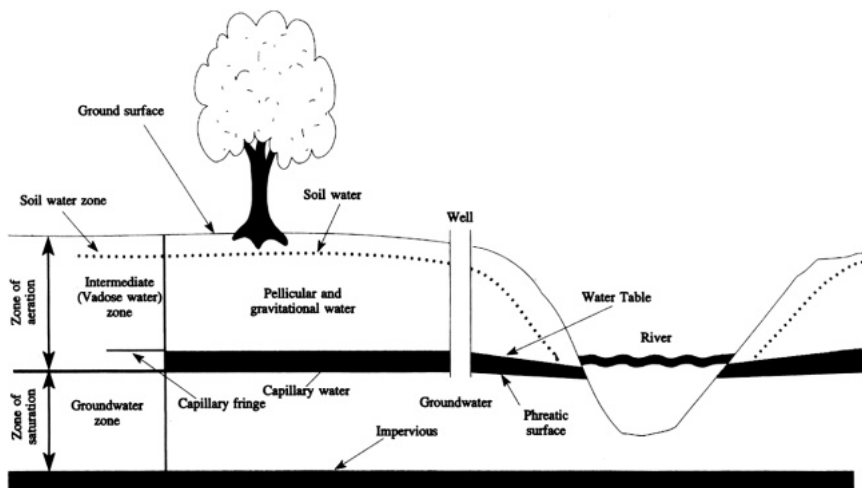


Figure 2.2. Subsurface Moisture Zones

Source: Bear and Verruijt (1987, p. 4).

to trace the movement of surface water contaminants. Climate, watershed and soil characteristics, crop management practices, and properties of the pesticides or chemical have been found to affect the magnitudes of the impacts (see Jury, Focht, and Farmer, 1987).

Concern over groundwater contamination is a relatively recent development, and as a result models that predict chemical leaching to groundwater are less developed than models that predict chemical runoff to surface water. To predict potential loadings to groundwater, a model is needed to trace the movement of the chemical from the application site down through the unsaturated (or aerated) zone and into the saturated zone (see Figure 2.2). The saturated zone is the area in which all the void spaces are filled with water; in the unsaturated zone, the void spaces are filled with both air and water, the proportion of which is important in modeling transport rates. The soil or root zone is a part of the unsaturated zone.

The chemical transport models developed in recent years include the Groundwater Loading Effects of Agricultural Management systems (GLEAMS, formerly CREAMS), the Pesticide Root Zone Model (PRZM), and the Hydrological Simulation Program-FORTRAN (HSPF). These large-scale models, and the transport component of these models, represents chemical movement primarily through the root or soil zone layer, excluding the saturated zone.

The fate of a pesticide or chemical applied to soil depends largely on two of

the pesticide's properties: persistence and solubility. Persistence is a measure of a chemical's rate of degradation and is usually measured in terms of a chemical's half-life. Solubility, sorption, and volatility determine how a compound partitions among water, soil, and air phases and determine whether the chemical is transported primarily with sediment or water. When a pesticide is applied, some of it will adhere to the organic carbon in the soil particles; this is called *adsorption*. Some of the pesticide will mix with soil water and move down with the soil water. An inverse relationship exists between the solubility of the pesticide and its sorption to soil. A partition coefficient value is used to describe the ratio of pesticide concentration in the adsorbed phase and the solution phase. The smaller the partition coefficient, the greater the concentration of pesticide in solution. Hydrologists have concluded that the greatest threat to groundwater through leaching is associated with a pesticide with a small partition coefficient and a long half-life.

### 2.3.1. *Pesticide Transport Models: An Overview*

Although the specific structure of the pesticide fate and transport models vary, most models contain some standard components. These include the following:

- *Surface runoff generation component* This describes the transformation of precipitation into runoff (precipitation will become runoff or infiltration). Surface runoff is a function of phenomena such as surface storage and evapotranspiration. The USDA Soil Conservation Service Curve Number (SCSCN) model is commonly used to estimate runoff. This method relates direct runoff to daily rainfall as a function of a curve number representing soil type, soil drainage properties, crop type, and management practice.
- *Soil and groundwater component* This describes pesticide movement through the unsaturated soil zone and may also describe movement into the saturated zone. Not all models trace the movement all the way through the unsaturated zone to the saturated zone.
- *Erosion component* This estimates soil loss due to erosion. This is important when determining potential for groundwater contamination because soil sediment is a medium of transport for adsorbed pesticides. A pesticide that is transported off the field via eroded soil is not available for leaching to groundwater. The Universal Soil Loss Equation (USLE), or a modification of the USLE, is frequently used to model erosion. The USLE is as follows:

$$A = R \times K \times LS \times C \times P,$$



where  $A$  is the computed soil loss in tons per acre per year,  $R$  is the rainfall factor,  $K$  is the soil erodability factor,  $LS$  is the slope length ratio factor and slope gradient ratio factor,  $C$  is the crop management factor, and  $P$  is the erosion control practice factor.

- *Soil adsorption and desorption component* This estimates the partitioning of a chemical between adsorbed particles and dissolved chemicals. This component estimates what portion of the chemical may be transported by soil sediment and what portion may be transported by soil water. It may also model volatilization and decay of the chemical.

Pesticide transport models can be divided into three broad categories: research models, screening models, and management models (Wagenet and Rao, 1990, provide a detailed discussion of these models). Research models provide quantitative estimates of water and solute movement, but usually involve extensive data demands on the system to be simulated. Management models are less data intensive and less quantitative in their ability to predict water and solute movement under various environmental conditions. Although most managerial and research models are field scale models, Wagenet and Rao (1990) indicate that there has been limited field testing of either the research or management models to date, and thus little attention has been focused on the so-called management models for the actual purpose of managing pesticide usage. The existing research models are useful for management purposes only if computer facilities and time are virtually unlimited.

Screening models are used to evaluate and compare pesticide fate and transport under alternative environmental conditions. The screening models have relatively low data demands and are designed to be relatively easy and inexpensive to use. One useful output of these models is to categorize chemicals into broad behavioral classes. These models have relevance in the pesticide registration process, where the properties of a pesticide that have not been field tested can be inferred from its characteristics. Several simple indexes useful to screen and rank pesticides in terms of their potential to leach into groundwater have been developed by Rao, Hornsby, and Jessup (1985). These ranking schemes are based on a screening model that determines the relative travel time needed for the pesticide to migrate through the unsaturated zone and the relative mass emissions (loadings) from the unsaturated zone into the groundwater.

Jury, Focht, and Farmer (1987) have also developed a screening model of the pesticide leaching process. This model relaxes the uniform first-order decay assumption for pesticide degradation in the unsaturated zone which characterizes the Rao, Hornsby, and Jessup (1985) model and replaces it with a biochemical decay relationship that decreases with soil depth. The results of both screening models indicate a significant dependence on site-specific soil and environmental

conditions, suggesting that these factors as well as the pesticide properties need to be taken into account when screening for groundwater pollution potential.

Wagenet and Rao (1990) caution that screening models have often been misused to estimate the environmental fate of a pesticide under a specified set of field conditions. They indicate that the recent interest in using models to predict the fate of pesticides in water and soils has provided an impetus to improve on the accuracy of management models. One of the most promising avenues to proceed for developing policy models is condensing the comprehensive descriptions provided by research models. Examples of such an approach are the recent changes to the PRZM and LEACHM models (see Wagenet and Hutson, 1989) and the model discussed in Section 2.3.3.

Leavesley, Beasley, Pionke, and Leonard (1989) indicate that entrainment of pesticides in surface runoff is a complex process that is difficult to define in terms of mathematical descriptions of the many physiochemical subprocesses involved. Success in simulating pesticide runoff is affected by the ability to cope with the diverse chemistry of the pesticides as well as by accurately simulating the hydro-logic and sediment-transport system.

**2.3.1.1. Pesticide Dissipation at the Soil Surface.** The primary state variable affecting pesticide entrainment is the amount of pesticide available in the soil surface during runoff. Application rates and methods determine the initial mass and its distribution between the crop canopy or crop residue and the soil. Available pesticide residue during runoff is dependent on subsequent rates of dissipation from both the canopy and the soil surface.

Processes contributing to pesticide dissipation are volatilization, photolysis, chemical and biological degradation, plant uptake, and leaching from the soil surface by infiltrating water. Each of these processes differs in its relative contribution depending on the particular pesticide in question. To date, no operational pesticide runoff model simulates all these processes independently. Most models simulate pesticide dissipation as a lumped first-order process. Research results indicate that a single first-order constant does not accurately represent dissipation during the entire period of persistence (Smith and Ferreira, 1987; Nash, 1980; Wauchope and Leonard, 1980). For most pesticides, dissipation is more rapid soon after application.

Pesticide dissipation rate also is a function of soil temperature, soil-water content, and other soil-environmental variables as outlined by Nash (1988). Where data are available, functional relations can be developed for many of those variables and incorporated into models (Smith and Ferreira, 1987). Work by Waler and coworkers (e.g., Walker, 1978) has demonstrated the utility of soil-water content and temperature relations for a limited number of pesticides. An extensive data base, as suggested by Nash (1988), will be needed before models

can make routine use of the more detailed dissipation relation. In the meantime, models will continue to use dissipation-rate contents or half-lives derived from either field or laboratory measurements also contained in files and data bases (Nash, 1988). The estimated range of error in selecting degradation-rate constants from literature sources for a given model application is with a factor of 2 (Rao and Davidson, 1980), provided judgment is used in selecting those determined for similar soils under similar conditions.

**2.3.1.2. Pesticide Partitioning Between Soil and Water.** The Freundlich equation,  $S = K_d C^N$ , or some modification of this basic equation is used almost universally to partition pesticide to the absorbed phase ( $S$ ) as a function of solution-phase concentrations ( $C$ ). The constants ( $K_d$  and  $N$ ) are specific to the particular pesticide and soil (or sediment) combination. Most models linearize this relation such that  $S = K_d C$ .

Because the primary absorber of non-polar pesticides is organic material, the equation may be rewritten as  $S = K_{OC} C \cdot OC$ , where  $K_{OC} = K_d OC$ ,  $OC$  being the fraction of organic carbon in the soil or sediment. The  $K_{OC}$  is dependent only on the particular pesticide. These simplifications are primarily for operational expediency. The pesticide components in the PRZM and GLEAMS models are based on these simplifying assumptions.

### 2.3.2. *Rutledge-Helgesen Groundwater Model*

One major disadvantage of the large-scale research simulation models is their lack of attention to the movement of chemicals through the unsaturated zone, although groundwater components have recently been appended to the PRZM and GLEAMS models. A second disadvantage to these models is simply the size and data requirements. Most utilize daily and often hourly climate data to simulate chemical movement.

As an alternative to the large-scale research simulation models, researchers have been developing simple models to evaluate pesticide groundwater pollution potential (Jury, Focht, and Farmer, 1987; Rao, Homsby, and Jessup, 1985; and Rutledge and Helgesen, 1989). These simpler approaches are more promising for use in regulatory BCA, and thus we illustrate the integration of a modified version of the Rutledge and Helgesen (RH) model into the net benefit specification.

The RH model is a model of chemical leaching to groundwater; it calculates pesticide residence time and the fraction of the pesticide remaining as functions of depth in the unsaturated zone. The model can simulate the presence of numerous lithologic layers in the unsaturated zone, continuous water content variation with zone depth, pesticide retardation, pesticide decay rates that differ among

layers, and root uptake of pesticide. The output of the model includes time and fraction of the pesticide remaining as functions of depth. The model also indicates variables to which groundwater contamination is most sensitive.

The RH model can be summarized using the following equations: the residence time, which is the time required for a pesticide particle to travel from land surface to the depth of interest,  $z_i$ , can be expressed as

$$t_i = \int_0^z \frac{1}{q} \{ \theta + (\rho_b)(K_d) \} dz, \quad (2.3)$$

where  $q$  denotes water flux per unit of surface area,  $q$  denotes residual moisture content,  $\rho_b$  denotes dry bulk density ( $\rho_b = \rho_s(1 - n)$ , where  $\rho_s$  is density of the solid matter in unsaturated zone and  $n$  is porosity), and  $K_d$  denotes partition (or distribution) coefficient ( $K_d = (K_{oc}P_{oc})/100$ , where  $K_{oc}$  denotes organic carbon partition coefficient of the pesticide and  $P_{oc}$  is percentage of organic carbon in the layer).

The model solves equation (2.3) to determine the time of a pesticide's transport to a given depth. The terms  $q$ ,  $q$ ,  $\rho_b$  and  $K_d$  are variable with depth, so RH's solution is by numerical integration.

One can approximate equation (2.3) for each layer with a linear approximation to the time integral:

$$t_i = z_i(1/q) (\theta + \rho_b K_d), \quad (2.3')$$

where the right side variables are set to their mean levels for that layer.

The fraction of the pesticide remaining at the depth of interest is calculated using equations representing the decay and root uptake processes. The fraction of the pesticide that remains after decay that occurs during its transport through the layer can be calculated by solving the equation for irreversible first-order reactions allowing for the known half-life of the pesticide:

$$RM_i = e^{-0.693(t_i/t(1/2))} \quad (2.4)$$

where  $RM_i$  denotes the fraction of the pesticide remaining after transport in the  $i$ th layer,  $t_i$  denotes the time of travel in the layer of interest in days, and  $t(1/2)$  denotes the half-life of the pesticide in the layer in days.

These latter values are assigned to each layer in the system based on empirically obtained figures from field and laboratory experiments. The percentage of the original pesticide applied to the land surface that remains after transport through more than one layer is the product of the value of RM for each layer.

Once again, we can use the approximation (2.3') to express RM for each layer  $i$  as

$$\log RM_i = (z_i D) / (t(1/2)q), \quad (2.4)$$

where

$$D = (\theta + p_b K_d)$$

and the percentage of the pesticide remaining after transport and decay through all layers would be

$$RM_z = \Pi RM_i = e^{\sum (z_i D) / (t(1/2)q)}. \quad (2.5)$$

The key parameters in determining the amount that remains are half-life, porosity, partition coefficient (which is determined by the organic carbon coefficient of the pesticide, and the percentage of organic carbon in each layer), water flux, and water content.

Root uptake is assumed to be proportional to the root uptake of water and evapotranspiration. To obtain the fraction remaining after these two processes (root uptake and decay) have occurred, the amount of pesticide remaining after decay is multiplied by the ratio of the amount of water flux at the depth of interest to the amount of water entering the ground at land surface:

$$m(x_j) = (RM_z)(q/w)(x_j), \quad (2.6)$$

where  $x_j$  denotes the amount of pesticide applied, and  $w$  denotes the rate at which water enters the ground. Equation (2.6) could be utilized in the damage function shown in equation (2.2).

A few remarks can be made with respect to the RH model or a modification of it. First, the potential of a given pesticide to contaminate groundwater is dependent on the pesticide having a sufficiently small organic carbon coefficient, which translates into a small  $K_d$ , and a sufficiently large half-life. This is consistent with the theoretical results from the physical science literature. Residence time is sensitive to depth to water table, as well as partition coefficient for the pesticide and moisture content.

To utilize the RH model, the following information would be required on soil (physical) and pesticide characteristics: the rate at which water enters the ground, the rate of deep percolation below roots, thickness of the root zone, depth to water table, density of solid matter in the unsaturated zone, type of material and depth in each layer of the soil, residual moisture (water) content, field capacity, porosity, and organic carbon content of the soil. The needed information pesticide characteristics include the organic carbon partition coefficient and half-life in each layer. In addition, one would also need data on pesticide application rates. Of the above information only the pesticide usage and the amount of water entering the ground at time of application would need to be collected on a regular basis. Presumably the other soil and pesticide characteristics are not time variant.

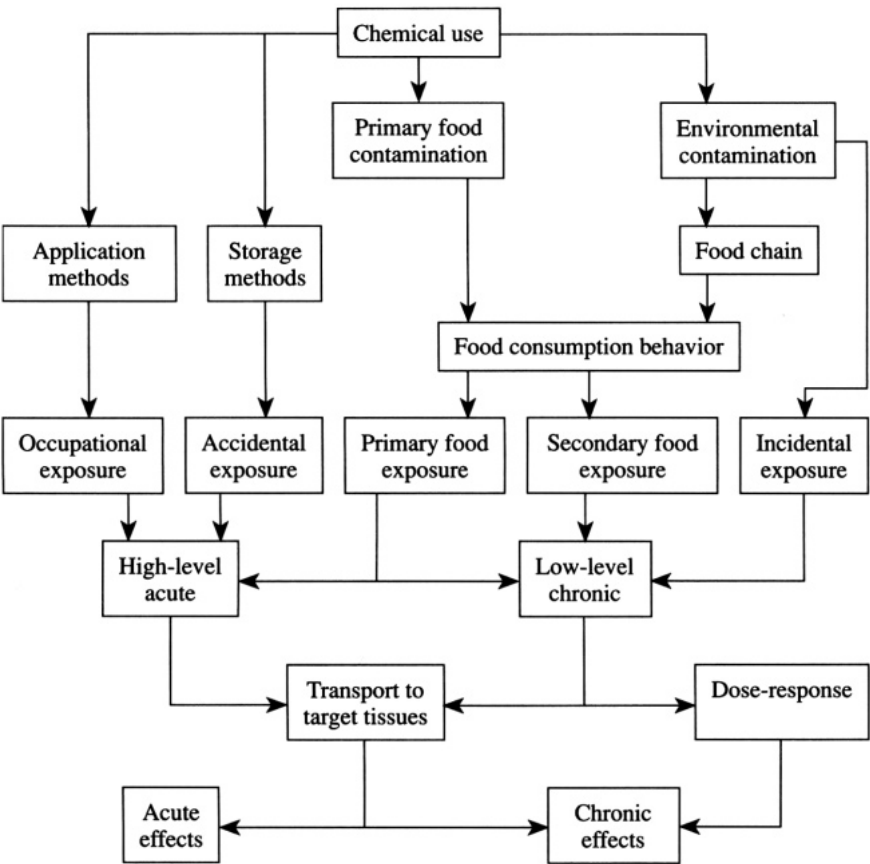


Figure 2.3. Schematic Representation of Health Effects Modeling

**2.4. Health Effects Modeling**

It is useful to decompose health effects modeling into two sequential stages illustrated in Figure 2.3: modeling exposure as a function of chemical use, application and storage methods, food contamination, and environmental contamination; and modeling health effects of acute and chronic exposure. Exposure modeling involves the transport of the chemical from application into the human body; modeling health effects involves knowledge of chemical and physical processes within the human body. Each of these components of the measurement of health effects involves its own set of data requirements and modeling

assumptions, and the scientific understanding of each is advanced in certain respects and deficient in others.

There is relatively good understanding and literature dealing with exposure mechanisms in occupational exposure and of acute health effects of many chemicals, but there is relatively poor understanding of environmental exposure and the associated chronic effects. The uncertainty surrounding the effects of low-level exposure means that valuation of these effects for policy analysis is particularly difficult. The problem of valuing health effects is compounded by the uncertainty about the effects themselves.

#### *2.4.1. Exposure Modeling*

Human health effects from exposure to some agricultural chemicals range from acute effects—illness and death—from occupational exposure and accidental poisonings to chronic dermal, respiratory, and neurologic effects and long-term effects such as cancer and reproductive problems.

The exposure pathways are inhalation (from spray materials or volatilization), ingestion (from occupational exposure, food residues on target crops or bioaccumulated through the food chain, and ambient concentrations in water), and dermal absorption (from occupational exposure). Acute exposure is associated primarily with occupational use of chemicals and accidental poisonings. Chronic exposure is associated with occupational exposure, food residues in crops and from bioaccumulation in the food chain, and from incidental exposure to environmental contamination.

Methods for inferring exposure range from direct monitoring of concentrations in humans to measurement of residues that may be introduced through inhalation, ingestion, or dermal absorption and to modeling to exposure using assumptions about partitioning chemicals into different components of the environment and resulting exposure.

#### *2.4.2. Food Residue Modeling*

Food residues can be estimated directly by sampling and testing food at the point of consumption. Alternatively, when this is not possible or is prohibitively expensive estimates of food residues can be computed based on assumptions about chemical applications to crops, retention of the chemical in or on the crop, degradation rates of the residues, and food consumption patterns. For example, in many of the regulatory decisions made by the United States Environmental

Protection Agency (USEPA), ingestion of a chemical is assumed to be a simple function of key parameters:

$$I = (1 - D)(R)(A)(Q),$$

where  $D$  is the average degradation rate from time of application to consumption,  $R$  is the residue concentration at application,  $A$  is the percentage of crop treated, and  $Q$  is average daily intake of foods treated.

One interpretation of this kind of formula is that it can provide an upper bound on possible residue ingestion. Alternatively, statistical distributions can be assigned to the parameters to produce a distribution of exposure. For example, suppose that  $R$  and  $A$  are known with some reliability not to vary, but  $D$  and  $Q$  are known to be distributed as approximately lognormal variates such that  $\ln(D) \sim N(\mu_d, s_d)$  and  $\ln(Q) \sim N(\mu_q, s_q)$ . Then  $I$  is lognormally distributed with mean and variance expressed as function of  $R$ ,  $A$ , and the parameters of the distributions of  $D$  and  $Q$ .

#### 2.4.3. Environmental Exposure Modeling

The standard approach to modeling environmental exposure is to assume that chemicals are distributed into various environmental compartments as functions of chemical properties, environmental factors, and chemical use according to equilibrium partitioning models (Mackay, Paterson, Cheung, and Neily, 1985). For example, it may be assumed that a pesticide applied to a rice paddy will be partitioned among air, water, soil, flora, and fauna. Symbolically,

$$C_{ij} = C_i(X_j, K_{ij}, E_i),$$

where  $C_{ij}$  is the concentration of the  $j$ th chemical in the  $i$ th partition,  $X_j$  is the chemical use,  $K_{ij}$  is the partition coefficient, and  $E_i$  is a vector of environmental factors.

The environmental contamination in each partition can be translated into exposure of the  $k$ th species through the expression

$$e_{jk} = \sum_i (C_{ij} A_{ijk}(\gamma)),$$

where  $e_{jk}$  is the exposure of the  $k$ th species to the  $j$ th chemical, and  $A_{ijk}(\mathbf{g})$  is the rate of uptake of the  $j$ th chemical in the  $i$ th partition by the  $k$ th species, and  $\mathbf{g}$  is a vector of individual species characteristics.

Thus, in general, total exposure of the  $k$ th species to the  $j$ th chemical is a function  $e_{jk}(X, K, E, \mathbf{g})$ , where the arguments are vectors of chemical used, partition coefficients, environmental characteristics, and species characteristics.



#### 2.4.4. *Occupational Exposure Modeling*

The occupational health literature is primarily concerned with determining the avenues of exposure of individuals in occupational settings, the link between exposure and health status, and interventions designed to reduce exposure (Spear, 1991). However, there is relatively little literature or experience on which to draw to devise models of occupational exposure that can be used to predict changes in exposure and health status under alternative policy or technology regimes.

One attempt to bridge this gap is the work conducted at the International Rice Research Institute (IRRI), where an overall indicator of health was constructed based on the treatment costs and work time lost because of impaired health, and variations in this indicator were explained as a function of pesticide use and individuals' personal characteristics. This relationship was then utilized in combination with an economic production model to simulate the effects on health status of changes in policy that affect pesticide use (Chapter 13). This modeling approach is described in further detail in the following section.

#### 2.4.5. *Health and Environmental Risk Assessment*

Estimation of human health effects as a function of exposure is referred to as *health risk assessment*, and estimation of impacts on other species is called *environmental risk assessment*. Two types of data are used for human risk assessment—epidemiological and toxicological. For environmental risk assessment, experimentation with the target species is also possible.

Epidemiological data are one method for assessing the acute health effects from exposure to toxic materials. Survey data from populations at risk, especially in occupational settings, are widely used for this purpose. Epidemiological methods work well in drawing inferences of acute effects because the magnitude of the health risk from acute exposure is much greater than the statistical error contained in epidemiological data. But for this same reason, epidemiological data appear to be of limited usefulness in detecting effects of chronic exposure (Gough, 1989). The risks of chronic effects such as cancer appear to be low relative to the statistical error in epidemiological data, thus frustrating efforts to draw useful inferences.

The alternative to epidemiological data is toxicological data (a dose-response relationship) obtained from experimentation with laboratory animals. The response in laboratory animals is then used to predict the response in humans. A review of both epidemiological data and toxicological data on carcinogenic substances recently found that they generally produce similar estimates of health

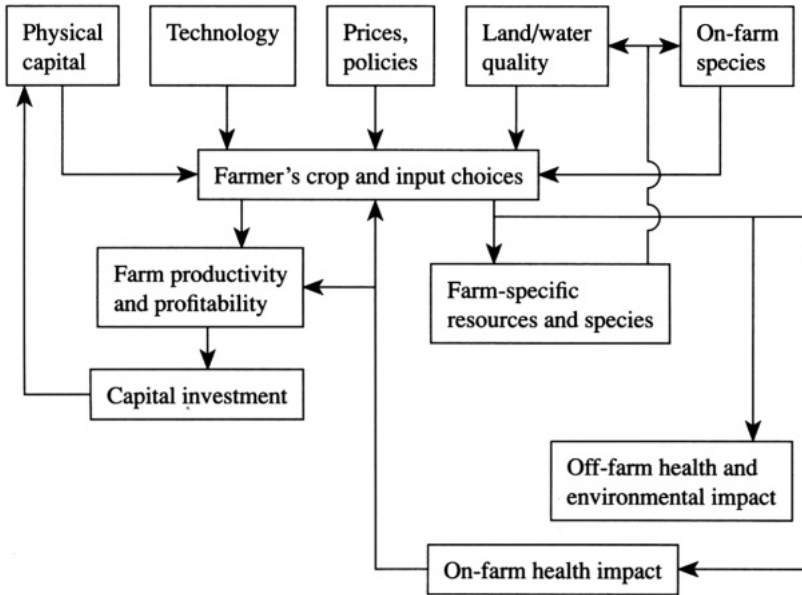


Figure 2.4. Production Model Linkages to On-Farm Resources and Off-Farm Environmental and Health Impacts

effects (Gough, 1989). The implication of this evidence is that toxicological data and exposure data can be combined to produce reasonable estimates of health effects, both acute and chronic, when epidemiological data are not available.

## 2.5. Economic Production Models

The economic behavior of agricultural firms can be represented as a two-level decision process corresponding to what economists refer to as the short run and the long run as illustrated in Figure 2.4. In the short run, firms make production decisions regarding outputs (types of crops and allocation of acreage among crops) and variable inputs (such as labor hours, fertilizer applications) taking as given the available technology and the existing stocks of physical capital and other resources used in production. These short-run decisions may be important in the analysis of externalities because they may include the use of agricultural chemicals, which are a source of pollution. In the long run, firms make investment decisions based on their expectations of future market conditions, technology, and resource availability. Their long-run decisions include the total acreage

of the farm operation and the quantities of physical capital employed. The long-run decisions may also have important consequences for externality generation. For example, the choice of tillage method (conventional tillage versus reduced or no-till) may have an impact on soil erosion and herbicide use and, hence, on pollution caused by chemical runoff.

### 2.5.1. *Producer Behavior in Static Models*

Farmers typically are assumed to be concerned with the private benefits and costs of their farm operations and thus do not take into account the longer-term impacts of their production activities on the ecosystem or on human health caused by agricultural pollution that occur off their farms. Farmers' longer-term capital investment decisions are not likely to have a direct impact on the generation of externalities. Under these circumstances, for analysis of externalities it is appropriate to model the short-run behavior of farmers as the maximization of the economic returns to management and capital, taking technology, management, and capital investment as given in each period. The analysis using a static model thus focuses on the output and input decisions that are made in each production period, given technological, economic, and resource constraints. For the measurement of externalities, the effects of the output and input decisions on physical resource stocks and living organisms in the ecosystem can, in turn, be measured. To measure the sequence of externalities generated over time, the biological system's changes can be fed back into the economic model to define the resource constraints on production in the next period, and the analysis can be repeated.

The short-run economic behavior of an agricultural producer can be modeled in terms of profit maximization; more generally risk management and other objectives can be introduced, but as a first-order approximation, profit maximization is a useful starting point. Conventional economic analysis of the profit-maximizing firm is based on the representation of the production process using the production function

$$Q_t = f(X_t, Z_t, \tau_t, r_t, S_t),$$

where  $Q_t$  is the maximum rate of output that can be produced in period  $t$  with variable inputs  $X_t$  (generally, a vector measuring labor, fertilizer, pesticides, and so on), fixed (capital) inputs  $Z_t$  (a vector measuring land, structures, machinery and tools, and so on), and parameter  $\tau_t$  representing the state of the technology (traditional seed variety versus modern seed variety, for example). The role of physical and biological resources in the production process is represented by the vectors,  $R_t$  (physical resources) and  $S_t$  (living organisms), in the production

function. The vector,  $R_t$ , could measure physical attributes of the resources used in production such as soil and water quality, and the vector,  $S_t$ , could measure populations of pests and natural enemies to pests.

The profit-maximization problem is represented as

$$\pi_t = \pi[P_t, W_t, Z_t, R_t, S_t, \tau_t]$$

This function is defined as the maximum profit the firm can earn, given  $P_t$ ,  $W$ ,  $Z$ ,  $\tau$ ,  $R_t$ , and  $S_t$ , by choosing levels of output and variable inputs,  $X_t$ . A remarkable property of the profit function is that the firm's profit-maximizing output, say  $Q^*$ , and its profit-maximizing input vector, say  $X^*$ , satisfy the following relationships:

$$Q_t^* = \partial\pi[P_t, W_t, Z_t, R_t, S_t, \tau_t]/\partial P_t = Q^*[P_t, W_t, Z_t, R_t, S_t, \tau_t] \quad \text{and} \\ X_t^* = -\partial\pi[P_t, W_t, Z_t, R_t, S_t, \tau_t]/\partial W_t = X^*[P_t, W_t, Z_t, R_t, S_t, \tau_t]$$

The complete production model is represented by the system of the three previous equations. Since the first equation measures short-run profit, it can be interpreted as measuring the producer surplus (net returns) used in benefit-cost analysis. For example, if a new seed variety were introduced, but prices, physical capital, and resource stocks were constant, the profit function would indicate the resulting change in producer surplus attributable to the new seed variety. The equation system also shows that the introduction of the new seed variety would generally have an effect on supply of output and on the demand for inputs. The introduction of a new variety would affect the demand for agricultural chemicals. This change in the use of agricultural chemicals would provide the link from the economic behavior of the farmers to the physical and biological models used to quantify pollution externalities.

The production model also shows that, generally, the economic relationships in period  $t$  depend on the resource stocks and living organisms represented by  $R_t$  and  $S_t$ . The economic model does not determine these variables in the current production period, rather  $R_t$  and  $S_t$  play the role of constraints on the production process. The values of  $R_{t+1}$  and  $S_{t+1}$  in the next period are determined in part by the production decisions in period  $t$ . Thus, the physical, biological, and economic sectors of the model interact dynamically according to the particular structure and parameterization of the systems of equations used to represent them. Given estimates of the parameters of these equations, initial values of the stocks,  $R_t$  and  $S_t$ , and predictions of the "forcing variables" such as prices that are determined outside of the model, the system of equations can be used to generate predictions of the time paths of agricultural production ( $Q_t$ ), input use ( $X_t$ ), and the physical and biological stocks,  $R_t$  and  $S_t$ .

### 2.5.2. Long-run Dynamic Investment Models

In some cases it is not appropriate to use a short-run static production model to analyze externality generation. A long-run model may be needed for a variety of reasons: because the choice of capital stock is important in the amount of externality created or because farmers do take externalities into account in their decision making or for long-run regional analysis of externality creation where the effect of the externality feeds back into the production process. To illustrate, consider a model in which physical capital evolves over time according to

$$Z_{t+1} = (1 - \delta)Z_t + V_t,$$

where  $\delta$  is the rate of capital depreciation and  $V_t$  is the rate of gross investment each period. Similarly, assume that the dynamics of the resources,  $R_t$ , and species,  $S_t$ , are given by

$$\begin{aligned} R_{t+1} &= h(R_t, X_t, Z_t) \text{ and} \\ S_{t+1} &= b(S_t, X_t, Z_t, R_t). \end{aligned}$$

The long-run maximization problem of the farmer is now defined as choosing the sequence of investments to maximize the present discounted value of profit from each period over the relevant planning horizon:

$$\text{Max } \sum \eta_t \{ \pi [P_t, W_t, Z_t, R_t, S_t, \tau_t] - U_t V_t \} + J[Z_{T+1}, R_{T+1}, S_{T+1}] \\ \{V_t\}$$

subject to

$$\begin{aligned} Z_{t+1} &= (1 - \delta)Z_t + V_t, \\ S_{t+1} &= B(S_t, X_t, Z_t, R_t), \text{ and} \\ R_{t+1} &= H(R_t, X_t, Z_t), \end{aligned}$$

where  $\eta_t$  is a discount factor depending on the rate of interest,  $U_t$  is the price of investment goods, and  $J$  measures the terminal value of the physical capital and resource stocks.

The above problem can be solved using optimal control or dynamic programming techniques. For example, the solution can be obtained by maximizing the following Hamiltonian equation:

$$\begin{aligned} H_t &= \eta_t \{ \pi [P_t, Q_t, Z_t, R_t, S_t, \tau_t] - U_t V_t \} + \lambda_t \{ (1 - \delta)Z_t + V_t \} \\ &\quad + \mu_t B(S_t, X_t, Z_t, R_t) + \rho_t H(R_t, X_t, Z_t), \end{aligned}$$

where  $\lambda_t$ ,  $\mu_t$ , and  $\rho_t$  are the constant variables for  $Z_t$ ,  $S_t$ , and  $R_t$  and represent the marginal capital values of these stocks. Maximizing the Hamiltonian and solving the resulting set of first-order conditions along with the constraints of the maximization problem gives an investment demand equation of the form

$$V_t = V[Z_t, S_t, R_t, P^t, W^t, \tau^t, U^t, \lambda_{T+1}, \mu_{T+1}, \rho_{T+1}],$$

where  $P^t = P_t, P_{t+1}, \dots, P_T$  and similar notation applies to other variables. Thus, the optimal investment in each period is a function of the current stocks of capital and resources, current and future prices, and the terminal values of the capital and resource stocks.

Using the investment demand equation for  $V_t$  together with the equations of motion for  $R_t$  and  $S_t$  and the equation for output supply and input demand one can solve for the long-run paths of all variables determined by the farmer. Note that the short-run and long-run models suggest a very different model of interaction between the economic, physical, and biological models. With the short-run economic model, economic decisions are made given the states of the physical and biological variables, and the physical and biological models are solved given the behavior of farmers. Time paths of the variables in each model are obtained by sequentially solving each model and using its results to condition the solution of the other model. In contrast, in the dynamic economic model, economic decisions are made taking into account the dynamics of the physical resource stocks and the population dynamics of species. Thus, the time paths for the economic, physical, and biological variables are determined jointly in the solution of the dynamic economic model.

## 2.6. Valuation of Market and Nonmarket Effects

The economic theory of social valuation is based on the principle of compensation: the value that an individual attaches in moving from one situation to another equals the amount of money the individual is willing to accept to make the change (if it has adverse consequences) or is willing to pay to make the change (if it has favorable consequences).

Individuals reveal their willingness to pay for market goods through market prices. Economic theory shows that when competitive markets exist for goods produced and consumed in the economy, market prices are the appropriate measure of social valuation of those goods. In practice, all markets do not function in exactly the manner assumed by economic theory, but market prices are, nevertheless, the best available approximate measures of the social values of market goods. If market prices are believed to be distorted by market imperfections or government policies, these distortions can be estimated and prices can be adjusted to better approximate social values.

More difficult valuation problems arise when markets do not exist for goods such as health or environmental quality. There are no market transactions on which to base inferences of willingness to pay for nonmarket goods or willingness to accept compensation for exposure to nonmarket "bads." The valuation of nonmarket goods is one of the principle issues addressed by environmental economics research over the past twenty years. While a number of theoretical

and practical difficulties remain in the pursuit of social valuations of nonmarket goods, much progress has been made.

### 2.6.1. *Valuation Theory*

The theory of valuation of nonmarket goods can be presented using the concept of the household production model (Smith and Desvousges, 1985). According to this view of behavior, market and nonmarket goods are demanded by households for use as inputs, in combination with the time and effort of household members, in a "household production process" that yields real services such as food to be consumed, clothing to be worn, health, shelter, recreation, and so forth.

Consider a simple example in which a market good  $x$  is combined with a nonmarket good  $q$  to produce a service flow  $z(x, q)$ . Money income is  $y$  and the utility function,  $U(y, z)$ , is an ordinal metric of well-being for the individual. To make the example more concrete, let  $z$  measure health, let  $x$  be actions to reduce exposure to pesticides, such as the use of protective clothing by a farmer who sprays pesticides, and let  $q$  measure pesticide use. Thus,  $z$  is increasing in  $x$  and decreasing in  $q$ . An important special case occurs when  $x$  and  $q$  are said to be perfect substitutes in the sense that  $z$  is a linear function of  $x$  and  $q$ ,  $z = a + x + bq$ , where  $a$  is a positive number and  $b$  is a negative number. The parameter  $a$  represents a base level of health when  $x$  and  $q$  are zero, and  $x$  is positive only if  $q$  is positive. In this special case, the effect of a one-unit increase in  $q$  can always be offset by a  $b$ -unit increase in  $x$ .

One measure of the value that the individual attaches to a change in  $q$  is the amount of money that would have to be spent to maintain the initial level of well-being indicated by the utility function  $U(y, z^0)$ . Because  $x$  and  $q$  are perfect substitutes, a one-unit increase in  $q$  necessitates an expenditure of  $((Px)b)$  dollars to maintain health and, thus, utility at the initial level, where  $Px$  is the price of  $x$ . An alternative way to look at this problem is to ask: if an individual were exposed to more  $q$  and health were reduced from level  $z^0$  to level  $z^1$ , how much would he have to be compensated to be as well off as before? The answer is that amount of additional income,  $Dy$ , such that  $U(y + Dy, z^1) = U(y, z^0)$ .

In general,  $x$  and  $q$  are not perfect substitutes. Consequently, the change in expenditure required to hold  $z$  constant is generally not the same as the expenditure required to hold utility constant. In the context of farmworker protection, for example, there are extra costs such as discomfort and inconvenience associated with the use of protective clothing, especially in tropical countries. Even though the wearing of protective clothing may protect a farmer's health, his utility will be lower wearing the clothing. Indeed, in the Philippine data analyzed by Pingali, Marquez and Palis, 1994 (also see Chapter 12), farmers did not use protective clothing.

An individual's observed behavior in response to a health risk generally cannot be such that utility is held constant. When an increase in exposure creates a need for the purchase of protective clothing, for example, the farmer's real income declines by that amount. Hence, to obtain an estimate of willingness to pay to avoid a health risk, an "income effect" associated with a change in exposure must be estimated. When the amount of money spent on  $x$  to substitute for  $q$  is a small part of income, this effect is negligible and can be disregarded. But the income effect may be very important for individuals with low incomes. When one observes poor farm workers who take few precautions to avoid health risk from pesticide exposure, it may be incorrect to infer that they are unaware of the health risks or that they attach a very low value to the health risks. An alternative explanation is that they are aware of the risks and attach a significant value to them, but that value is less than the income that would be forgone from buying the protective clothing and the disutility associated with wearing it. This could be another explanation for the observation that poor Philippine farmers rarely use protective clothing.

It should be emphasized that a fundamental assumption underlying the household production model is that the individual knows the relationship between nonmarket goods and their well-being represented by function  $z(x, q)$ . In the pesticide example, the farm worker must know that exposure to a pesticide may pose a health risk. It is important to attempt to verify that this key assumption is valid before attempting to use the household production theory to construct a valuation methodology. The lack of knowledge about the health effects of pesticides provides another possible explanation for the failure of farmers to take self-protection measures.

### 2.6.2. *Nonmarket Value Estimation*

The above discussion shows that, in theory, it is possible to infer willingness to pay by observing behavior that is related to the consumption of the nonmarket good. The willingness to pay to avoid a health risk can be used to infer the value people attach to that health risk. Similarly, people may be willing to pay for environmental quality because it is of value to them in their recreation activities or simply because they value the existence of certain environmental amenities even if they do not use them.

The theoretical framework described above has several additional implications for nonmarket value estimation in the development context. First, the model can be used to formulate hypotheses about the effect of income on valuation. At low income levels, subsistence requires a minimum of food, shelter, clothing, and health. As income rises, demand for some aspects of health may increase



along with demand for environmental quality. Similarly, at low income levels life expectancy is short, and individuals may attach less importance to problems associated with chronic exposure than to problems of acute exposure. There appears to be little or no empirical research on this set of questions to date, however.

The two basic methods for quantifying nonmarket values parallel the two ways described above for inferring willingness to pay to avoid pesticide exposure. Following that example, the first method is to collect data on actual behavior in relation to the nonmarket good such as health. Survey methods can be used to obtain data, for example, on pesticide application procedures, expenditures on and use of protective clothing, and income, and other relevant data. As noted above, it is important to account for the effect of income changes on the inferred values of health risk.

It is also possible to infer valuation of nonmarket goods by eliciting responses about how people would respond to hypothetical situations (Mitchell and Carson, 1989). For example, a survey can be conducted in which respondents are asked to say how much they would be willing to pay to avoid certain health risks or how much they would be willing to accept to be compensated for exposure to health risks. This approach would elicit measurements of the  $\Delta y$ , mentioned in the above example, associated with particular changes in health or environmental quality. A similar approach is to ask respondents to rank alternative situations involving different combinations of market (income) and nonmarket (health, environmental quality) goods. Researchers can use this information to infer the respondents' willingness to pay or willingness to accept compensation for changes in the nonmarket goods.

### 2.6.3. *Implied Valuation*

It was noted above that the nonmarket valuation methods require the assumption that individuals understand the link between some action, such as pesticide exposure, a nonmarket good such as health, and their personal well-being. This assumption has been found to be questionable in high-income countries such as the United States, where information about such linkages is available to the general population at low cost, unless efforts are made to inform respondents about these linkages. This assumption may be even more questionable in a low-income, rural farm setting where information about these linkages is not readily available or literacy limits individuals' ability to understand them. Under these conditions, an alternative approach to valuation is needed that does not depend on this key assumption.

One alternative approach is to measure the social valuation of health and

environmental risks implied by public policies that are in use or that could be used to remedy a problem. For example, the economic costs of banning a chemical pesticide can be estimated. If a government were willing to undertake such a policy, it can be assumed that it judges the benefits of the pesticide ban to be at least as great as the costs.

To illustrate this approach to social valuation, return to the production model discussed in Section 2.5. Using either a static or dynamic version of a production model, a policy constraint such as a restriction on pesticide use can be imposed. The resulting change in crop production can be introduced into a partial or general equilibrium market model to estimate the economic effects this change in production has on consumers and producers. The change in consumer and producer welfare can be interpreted as a lower bound on the benefits of the restriction on pesticide use.

The assumption that public policy is undertaken when social benefits exceed social costs can be questioned on several grounds. Certainly, experience in many countries indicates that policies have often been implemented that would not pass a benefit-cost test. Another problem concerns the distribution of benefits and costs. Urban consumers may want to restrict pesticide use to ensure food safety, but rural consumers may not be willing to pay for such safety. Yet another problem concerns paternalism. Policymakers often assume they know what is good for other groups in society, such as farmers. Restrictions on pesticide use may be imposed in the name of farm safety whether or not the farmers themselves would be willing to give up the use of pesticides for safety reasons.

#### 2.6.4. *Productivity and the Value of Health*

Another indirect approach to valuation is explored by Antle and Pingali (1994). In this approach, the costs of pesticide exposure on farmer health and the effects of health on farm productivity are estimated and then used to determine the total impact of pesticides on productivity. Symbolically, the model is

$$\begin{aligned} I &= I(N^s, N^h) \\ C &= C(Y, w^s, w^h, I) \\ Q^i &= \partial C / \partial w^i \\ N^i &= Q^i / A^i, i = s, h \\ P &= \partial C / \partial Y, \end{aligned}$$

where  $I$  = health impairment variable;  $N^i$  = number of application,  $i = s, h$  ( $s$  = pesticides and  $h$  = herbicides);  $C$  = cost of production;  $Q$  = quantity of insecticide or herbicide;  $A^i$  = average application rate of quality-adjusted insecticide

or herbicide;  $w^i$  = quality-adjusted insecticide or herbicide price;  $Y$  = yield; and  $P$  = output price.

The first equation represents the relationship between pesticide use (number of applications of insecticide and herbicide) and health, where this equation was estimated controlling for individuals' characteristics such as general health status, age, and behavior (smoking tobacco and drinking alcohol). The second equation relates cost of production to crop output, input prices, and the farmer's health. The other equations are derived from the economic behavior of the farmer and represent input use behavior and production behavior. Note that the quantity of input used ( $Q^i$ ) is related to numbers of applications of pesticides ( $N^i$ ) by specifying that  $N^i = Q^i/A^i$ , where  $A^i$  is the average application rate.

There are various policy scenarios under which pesticide use could be reduced. All pesticide use could be restricted equally, or use could be restricted according to productivity or toxicity criteria. In the case of Philippine rice production, the insecticides are the most toxic substances (categories I and II, according to the World Health Organization system of classification), whereas the herbicides used are relatively less toxic (category IV). An efficient policy would generally not regulate insecticides and herbicides equally if their health and productivity characteristics are different.

## 2.7. Model Integration

The various components of the analysis need to be brought together into an integrated model for estimation of the market and nonmarket effects of chemical use. These effects can then be utilized in a formal cost-benefit analysis framework described in Section 2.2. Table 2.1 presents the components of an integrated model. This table also identifies the input data and parameters that such a model might use, the linkages between the model components, and the outputs it would produce.

### 2.7.1. Methodological Issues

Several methodological issues arise as the model components are brought together into an integrated model. Successful integration requires compatible mathematical structures for numerical models and consistent statistical criteria need to be developed. In addition, several conceptual differences in model approaches exist across disciplines need to be taken into consideration. The most important point to be emphasized is the need for communication across disciplinary lines.

**Table 2.1. Representative Data, Parameters, and Outputs of an Integrated Model for Assessment of Social Costs of Pesticide Use**

|            | <i>Physical/Environmental</i>       |                          | <i>Model Components Health</i> |                       | <i>Economic</i>       |
|------------|-------------------------------------|--------------------------|--------------------------------|-----------------------|-----------------------|
|            | <i>Soil/Water<br/>1a</i>            | <i>Species<br/>1b</i>    | <i>Occupation<br/>2a</i>       | <i>Food<br/>2b</i>    | <i>3</i>              |
| Input Data | Weather                             | Physical characteristics | Pest management<br>Acute risk  | Consumption data      | Prices, acres         |
|            | Soil type                           |                          |                                | Chronic risk          | Management practices  |
|            | Slope<br>g.w. depth                 |                          |                                |                       |                       |
| Parameters | Degree rates<br>Partial coefficient | Uptake                   | Uptake                         | Degree rates          | Technology Policy     |
| Links      | 1.b, 2.b<br>3                       | 2.b, 3                   |                                |                       | 1.a, 1.b.<br>2.a, 2.b |
| output     | Water quality                       | Mortality                | Acute effect                   | Acute, chronic effect | Crop production       |
|            | Soil quality                        | Bioaccumulation          |                                |                       | Profit                |

Basic methodological issues must be addressed in reconciling the different approaches to research methodology that are used in the various disciplines.

**2.7.1.1. Physical Versus Behavioral Modeling.** First, there is a conceptual difference between the physical modeling, which relies on physical constants, and behavioral models based on the assumed optimizing behavior of people. The structure of a physical model is invariant to changes in government policy, for example, but a model of farmer behavior may need to take into consideration the way farmers form expectations about policy. Consequently, the structure of a behavioral model may change over time as policy and other parameters change. The change in the structure of the behavioral model may in turn alter the linkages between the physical and economic models.

**2.7.1.2. Experimental Versus Nonexperimental Data.** The physical and biological sciences rely primarily on data generated by controlled experiments. Economic analysis is generally based on nonexperimental data. Econometrics is devoted to the modification of classical statistical analysis so that valid inferences can be drawn from nonexperimental data. The differences in statistical methods need to be reconciled in the design of data surveys and research methodologies.

**2.7.1.3. Modeling Approaches.** Various disciplines find particular mathematical structures to be appropriate for their problems. For models to be integrated across disciplines, all disciplinary model components must be consistent with the ultimate goal of linking the models for valuation of nonmarket effects.

**2.7.1.4. Selecting the Unit of Analysis: The Aggregation Problem.** A basic methodological problem arises in any attempt to integrate the physical, health, and economic model components into a coherent whole: each component relates to a particular unit of analysis on which cost-benefit analysis should be based. The solution to this problem is to provide a statistical representation of the integrated model that can be defined over a common unit of analysis and then to statistically aggregate to the unit of measurement meaningful to cost-benefit analysis.

## 2.7.2. *A Statistical Approach to Model Integration*

A key factor that needs to be taken into account in the modeling methodology is the heterogeneity of the physical environment and the related heterogeneity of agricultural production practices and associated environmental and health effects of those practices. For example, an analysis of the environmental fate of a pesticide based on a set of partition coefficients may be reasonable for a well-defined physical unit—say, 100 square meters of surface area—over which a specific set of parameters and input data are valid. But such a unit is generally much smaller than the economic or geophysical unit of analysis relevant to the assessment of social costs of chemical use. The relevant unit of analysis for social cost assessment may be as small as a farm or as large as an entire regional watershed.

To address the heterogeneity problem, an aggregate unit of analysis can be defined as a function of the problem context: for water quality problems, for example, the unit of analysis may be the land contained in a particular watershed. The land in the aggregate unit of analysis can, in turn, be disaggregated into a sufficiently small unit over which a valid set of physical and economic data and parameters can be defined. Let us call such a unit a *plot*. Associated with each plot is a vector of physical characteristics represented by  $w$ .  $w$  may include physical characteristics such as depth to groundwater on the plot, the partition coefficients for the plot, the slope and elevation of the plot, and so forth. A stylized physical model can then be written as  $C(X, w)$ , where  $C$  is the vector of contaminant levels associated with the environmental partitions in the model (e.g., soil, air, water), and  $X$  is a vector of chemical applications.

As shown in Section 2.5, a farmer's chemical use decisions are functions  $X(P, \psi, \tau, \omega)$ , where  $P$  represents prices of outputs and inputs,  $\psi$  represents policy parameters, and  $\tau$  is technology parameters, and  $\omega$  is as defined above. Let the environmental characteristics of each plot of land in the region be fixed at a point of time and distributed across plots according to a distribution defined by a parameter,  $\theta$ . This distribution of environmental attributes induces a joint distribution for input use  $X$ , crop production  $Q$ , and contamination levels. Defined this joint distribution as  $\phi(Q, X, C|P, \psi, \tau, \theta)$ .

### 2.7.3. Statistical Aggregation

The joint distribution,  $\phi$ , provides a basis for statistical aggregation across the plots into quantities that can be used to conduct policy analysis at the aggregate level. For example, by integrating  $X$  and  $Q$  out of  $\phi$ , a marginal distribution of contamination can be defined:  $(C|P, P, \psi, \tau, \theta)$ . Using this distribution, the tradeoffs between, say, mean chemical use and groundwater contamination can be estimated. This information can be combined with validation data to estimate the value associated with groundwater contamination. In addition, an aggregate pollution function can be obtained by taking the expectation of  $C$  with respect to this marginal distribution, and that relationship can be used for analysis of pollution policy (see Antle and Just, 1991, for further discussion of these procedures).

To illustrate the statistical aggregation procedures, consider the following example based on the assumption that contamination is a log-linear function of input use and a physical variable,  $\omega$ ,  $\ln C = \alpha \ln X + \beta \ln \omega$ , where  $\alpha$  and  $\beta$  are positive parameters. Also assume, as is frequently done in statistical modeling, that  $X$  and  $\omega$  follow lognormal distribution such that

$$\begin{bmatrix} \ln X \\ \ln \omega \end{bmatrix} \sim N[\mu, \Sigma|P, \psi, \theta],$$

where  $\mu$  is a  $(2 \times 1)$  vector of means and  $\Sigma$  is a  $(2 \times 2)$  covariance matrix. It follows that  $C$  is lognormally distributed and its mean and variance are function of  $\alpha, \beta, \mu, \Sigma, \mu$  and are, in turn, functions of  $P, \psi$ , and  $\theta$ . Thus, for example, the population mean contamination level can be expressed as a function of the population mean level of chemical use. This relationship can be employed in policy analysis. For example, if a dollar value could be attached to a specified reduction in environmental contamination, these data can be used in a cost-benefit analysis of policies to reduce pesticide use.

## 2.8. Sustainability, Total Factor Productivity, and Benefit-Cost Analysis

The issue of sustainability has been a fashionable topic over the last decade, but as Solow (1992) indicates, "discussion of sustainability has been mainly an occasion for the expression of emotions and attitudes. There has been very little analysis of sustainable paths . . . so that we have little idea of what would be required in the way of policy and what sorts of outcomes could be expected."

If one adapts the Lynam and Herdt (1989) or Solow (1992) definition of sustainability or a sustainable path—that sustainability is the capacity of a system to maintain output at a level approximately equal to or greater than its historical average, or a sustainable path allows a future generation the option of being as well off as its predecessors—then the connection to benefit-cost analyses and the dynamic framework presented earlier in this paper for analysis of production systems is apparent. The standard of living achieved by future generations or the level of measured output depends on the endowment—human, conventional capital, and natural resource and environmental capital stocks. A sustainable system or path is not necessarily one that conserves every single resource but rather replaces what it takes from its endowment. And as Solow (1992) indicates, "What matters is not the particular form that the replacement takes, but only its capacity to produce . . . those depletion and investment decisions are the proper focus. . . . Tradeoffs and substitutions are not only permissible, they are essential. . . . The terms of which one form of capital should be traded off against another, i.e., determining shadow values, involve a certain amount of guesswork, but it is better that the guesswork be based on careful research than that the decision be judged."

The interdisciplinary framework proposed in this research is a systematic approach to determining the tradeoffs, or the shadow value, attached to the use of the environmental, natural resources, and human capital assets. The work of Hartwick (1991) discusses the need to correctly adjust national accounting procedures for changes in the quantity and quality of environmental and natural resource capital. Farrell and Capalbo (1986) and Lynam and Herdt (1989) discuss the connection with conventional measures of productivity and, in particular, to include environmental and natural resource stocks in the aggregation of capital and to adjust productivity measures for changes or determination in these stock levels. Such adjustments require interdisciplinary research on the value to society of these changes.

## 2.9. Conclusions

The basic premise of this paper has been the need to construct a comprehensive framework for valuing private and social benefits and costs of pesticide use.

Such an approach is essential as input into making informed policy decisions on pesticide/chemical use, and as input into addressing more encompassing issues such as long-run sustainability of pesticide and chemical practices, and dynamic productivity measures for the agricultural sector.

The following three points highlight the research needs for valuing the social costs of pesticide use. First, although benefit-cost analysis provides the foundation for developing the framework for integrating the interdisciplinary research for valuing chemical externalities, further research is needed to reduce the uncertainties in physical, economic, and health modeling. Second, the data needed to identify the potential for environmental damage associated with pesticide use and to assess the net benefits of alternative schemes to mitigate environmental damages and health impacts are location and chemical specific. These information needs include the characteristics of the pesticide and the agroecological factors that determine the probability of its fate in the environment, the health dose-response relationships needed to determine human health impacts, farm-level data on management practices and application amounts, and consumer preferences for changes in health risks and environmental quality. Finally, while there is ongoing research addressing some of the physical modeling requirements, there is also a need for further development of valuation methods suitable for valuing the kinds of risk associated with pesticide contamination.

## Notes

1. Damages are often used interchangeably with the notion of benefits. In effect, damages represent the “mirror image of benefits, . . . what is lost in moving from the hypothetical cleaner state to the existing level of pollution” (Freeman, 1979, p. 3).

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# 3

## FARMER PERCEPTIONS, KNOWLEDGE, AND PESTICIDE USE PRACTICES

H. Warbuton, F.G. Palis and P.L. Pingali

Rice production accounted for about half of the total insecticides, over 80 percent of herbicides, and 4 percent of fungicides sold in the Philippines in 1987 (APIP, 1991). Molluscicides have also been used in small quantities since 1987 to control the golden snail (Warburton and Pingali, 1993). Fifty-five percent of the pesticides sold in the country are insecticides, followed by herbicides (19 percent) and fungicides (15 percent) (Rola and Pingali, 1992). However, the total quantities of pesticides used in the Philippines are small compared with heavy users such as South Korea and Japan. Rice agrochemicals in the country accounted for only 2 percent of the world market value in 1988 (Woodburn, 1990).

The most common pesticides sold are mainly hazard category I and II pesticides, which are highly hazardous chemicals according to the World Health Organization (WHO) classification. Herbicides in general are less toxic than insecticides or molluscicides. While four insecticides were recently banned by the Philippine Fertilizer and Pesticide Authority (FPA), a large number of pesticides commonly used in the country are subject to bans or restrictions in other countries (Table 3.1).

The risks to human health caused by these pesticides have been widely researched, but pesticide risks to health as perceived by farmers and laborers is one area that has so far received little attention. This is particularly true in

Table 3.1. Bans and Restrictions on Selected Pesticides Used in Laguna and Nueva Ecija, Philippines, 1991

| <i>Common Name</i>              | <i>Family<sup>a</sup></i> | <i>Chemical<br/>a.i. Hazard<br/>Category<sup>b</sup></i> | <i>Formulation<br/>Hazard<br/>Category<sup>c</sup></i> | <i>Bans and Restrictions in<br/>Philippines and Other<br/>Countries<sup>d</sup></i>                                      |
|---------------------------------|---------------------------|----------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| <i>Insecticides:</i>            |                           |                                                          |                                                        |                                                                                                                          |
| Methyl-<br>parathion            | OP                        | IA                                                       | 1                                                      | U.S.: restricted use<br>U.K.: not registered<br>Japan, Bangladesh, Sri<br>Lanka: banned<br>China: restricted use         |
| Aldrin                          | OC                        | IB                                                       | 2                                                      | Philippines: restricted use<br>U.S.: no longer registered<br>U.K., Korea: banned<br>Other Asian countries:<br>restricted |
| Azinphos-ethyl                  | OP                        | IB                                                       | 1                                                      | Philippines: ban proposed<br>Dec. 31, 1992<br>U.S.: not registered<br>U.K.: azinphos-methyl<br>professional use          |
| + BPMC                          | OP/C                      |                                                          |                                                        | India, China, Thailand:<br>banned                                                                                        |
| Carbofuran                      | C                         | IB                                                       | 2                                                      | U.S.: restricted use<br>U.K.: professional use                                                                           |
| Edifenphos                      | OP                        | IB                                                       | 1                                                      | U.K.: not registered<br>Sri Lanka: restricted use                                                                        |
| Formetanate                     | C                         | IB                                                       | 1                                                      | U.K.: not registered                                                                                                     |
| Methamidophos                   | OP                        | IB                                                       | 1                                                      | U.K.: not registered<br>Bangladesh, Indonesia, Sri<br>Lanka: restricted                                                  |
| Methomyl                        | C                         | IB                                                       | 1                                                      | U.S.: restricted use<br>Indonesia, Sri Lanka,<br>U.K.: restricted use<br>Malaysia: banned                                |
| Monocrotophos                   | OP                        | IB                                                       | 1                                                      | Philippines: ban proposed<br>Dec. 31, 1992<br>U.S.: no longer registered                                                 |
| Monocrotophos<br>+ cypermethrin | OP/P                      |                                                          |                                                        | U.K.: not registered<br>Indonesia, Malaysia, China:<br>restricted use                                                    |
| Triazophos                      | OP                        | IB                                                       | 1                                                      | U.S.: not registered                                                                                                     |

Table 3.1. (continued)

| <i>Common Name</i>     | <i>Family<sup>a</sup></i> | <i>Chemical<br/>a.i. Hazard<br/>Category<sup>b</sup></i> | <i>Formulation<br/>Hazard<br/>Category<sup>c</sup></i> | <i>Bans and Restrictions in<br/>Philippines and Other<br/>Countries<sup>d</sup></i>                                                                                                                                      |
|------------------------|---------------------------|----------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BPMC                   | C                         | II                                                       | 2                                                      | U.K., Indonesia: restricted use<br>U.S.: not registered<br>U.K.: not registered                                                                                                                                          |
| + Endosulfan           | C/OC                      |                                                          |                                                        |                                                                                                                                                                                                                          |
| + Phenthoate           | C/OP                      |                                                          |                                                        |                                                                                                                                                                                                                          |
| Carbaryl               | C                         | II                                                       | 2                                                      | U.S.: registered general use<br>Indonesia: restricted use                                                                                                                                                                |
| Chlorpyrifos           | OP                        | II                                                       | 2                                                      | U.S.: registered general use<br>Indonesia: restricted use                                                                                                                                                                |
| Chlorpyrifos<br>+ BPMC | OP/C                      |                                                          |                                                        | U.S.: not registered                                                                                                                                                                                                     |
| Cyhalothrin            | P                         | II                                                       | 4                                                      | U.K.: not registered                                                                                                                                                                                                     |
| Cypermethrin           | P                         | II                                                       | 4                                                      | U.S.: registered general and<br>restricted use                                                                                                                                                                           |
| DDT                    | OC                        | II                                                       | 2                                                      | Sri Lanka: restricted use<br>Philippines: restricted use<br>U.S.: very restricted use<br>Japan, U.K., Bangladesh,<br>Indonesia, Thailand,<br>Korea, Malaysia, Sri<br>Lanka,<br>China: banned<br>Pakistan: restricted use |
| Deltamethrin           | P                         | II                                                       | 4                                                      | U.S.: not registered<br>U.K.: professional use                                                                                                                                                                           |
| Diazinon               | OP                        | II                                                       | 2                                                      | U.S.: registered general use<br>Indonesia: restricted use                                                                                                                                                                |
| Endosulfan             | OC                        | II                                                       | 2                                                      | Philippines: restricted use,<br>proposed reduction from<br>35% to 5% EC,<br>Dec. 31, 1992                                                                                                                                |
| Endox                  |                           |                                                          |                                                        | U.S.: registered general<br>use<br>Indonesia, Bangladesh,<br>Sri Lanka, Thailand:<br>restricted use                                                                                                                      |
| Fenitrothion           | OP                        | II                                                       | 2                                                      | U.S.: registered general use<br>Indonesia: restricted use                                                                                                                                                                |

Table 3.1. (continued)

| <i>Common Name</i>        | <i>Family<sup>a</sup></i> | <i>Chemical<br/>a.i. Hazard<br/>Category<sup>b</sup></i> | <i>Formulation<br/>Hazard<br/>Category<sup>c</sup></i> | <i>Bans and Restrictions in<br/>Philippines and Other<br/>Countries<sup>d</sup></i>                                               |
|---------------------------|---------------------------|----------------------------------------------------------|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| + Malathion               | OP                        |                                                          | 3                                                      | U.S.: not registered                                                                                                              |
| Fenvalerate               | P                         | II                                                       | 4                                                      | U.S.: registered general<br>and restricted use<br>Sri Lanka: restricted use                                                       |
| Isoprocab                 | C                         | II                                                       | 3                                                      | U.S.: not registered<br>U.K.: not registered                                                                                      |
| Lindane                   | OC                        | II                                                       | 2                                                      | U.S.: registered general and<br>restricted use<br>Thailand: restricted use <sup>c</sup><br>Bangladesh, Japan: banned <sup>c</sup> |
| Profenofos                | OP                        | II                                                       | 2                                                      | U.K.: not registered                                                                                                              |
| Ethofenprox               | PH                        |                                                          | 3                                                      | U.K.: not registered                                                                                                              |
| Malathion                 | OP                        | III                                                      | 3                                                      | U.S.: registered general use<br>Indonesia: restricted use                                                                         |
| <i>Molluscicides:</i>     |                           |                                                          |                                                        |                                                                                                                                   |
| Isazophos                 | OP                        | IB                                                       | 2                                                      | U.K.: not registered<br>Indonesia: restricted use                                                                                 |
| Fentin acetate            | T                         | II                                                       | 2                                                      | Philippines: ban 1990<br>U.S.: not registered<br>U.K.: (+ MANEB)<br>professional use                                              |
| Fentin chloride           | T                         | II                                                       | 2                                                      | Philippines: ban 1990<br>U.S., U.K.: not registered                                                                               |
| Fentin<br>hydroxide       | T                         | II                                                       | 2                                                      | Philippines: withdrawn<br>1991<br>U.K.: professional use                                                                          |
| Cartap hydro-<br>chloride | TC                        | II                                                       | 3                                                      | U.K.: not registered<br>Indonesia: restricted use                                                                                 |
| Niclosamide               |                           | III                                                      | 4                                                      | U.S.: restricted use<br>Japan: restricted use                                                                                     |
| Metaldehyde               |                           | IV                                                       | 4                                                      | U.K.: registered general use                                                                                                      |
| <i>Herbicides:</i>        |                           |                                                          |                                                        |                                                                                                                                   |
| 2,4-D                     | PH                        | II                                                       | 2                                                      | U.S.: registered general use<br>Sri Lanka: restricted use                                                                         |
| + Thiobencarb             |                           |                                                          | 2                                                      | U.S.: registered general use                                                                                                      |
| + Butachlor               |                           |                                                          | 3                                                      | U.S., U.K.: not registered                                                                                                        |

Table 3.1. (continued)

| <i>Common Name</i> | <i>Family<sup>a</sup></i> | <i>Chemical a.i. Hazard Category<sup>b</sup></i> | <i>Formulation Hazard Category<sup>c</sup></i> | <i>Bans and Restrictions in Philippines and Other Countries<sup>d</sup></i> |
|--------------------|---------------------------|--------------------------------------------------|------------------------------------------------|-----------------------------------------------------------------------------|
| + Piperophos       |                           |                                                  | 3                                              | U.S., U.K.: not registered                                                  |
| Thiobencarb        | TC                        | II                                               | 3                                              | U.K.: not registered                                                        |
| MCPA               | PH                        | III                                              | 2                                              | U.K.: registered general use                                                |
| Butachlor          | A                         | IV                                               | 4                                              | U.S., U.K.: not registered                                                  |
| Pretilachlor       | A                         | IV                                               | 4                                              | U.K.: not registered                                                        |
| Oxadiazon          |                           | IV                                               | 4                                              | U.S.: registered general use                                                |

a. A = acetamides; c = carbamates; OC = organochlorines; OP = organophosphates; P = pyrethroid; PH = phenoxy; T = organotins; TC = thiocarbamates.

b. Hazard category of active ingredient as defined by WHO: IA = extremely hazardous; IB = highly hazardous; II = moderately hazardous; III = slightly hazardous; IV = product unlikely to present acute hazard in normal use.

c. Formulation hazard category of the most commonly sold product in the Philippines, as defined by the Philippine Fertilizer and Pesticide Authority (FPA), based on WHO guidelines.

d. Not registered = if a chemical is not registered, it cannot be sold in the United States or United Kingdom; restricted use = chemical can only be used for specific registered uses; professional use = applicators must be trained and licensed (reference: U.S. EPA Registration Status, EPA database, March 1992; Handbook on the Use of Pesticides in the Asia = Pacific Region, ADB, 1987; Pesticides 1991: Pesticides Approved Under the Control of Pesticides Regulations, UK MAFF, 1991).

e. Restrictions unclear (ADB, 1987: 83, 234).

developing countries, where it is often assumed that farmers, the major pesticide users, are not fully aware of the risks they face or are too poor to take preventative actions. Their perceptions, however, are important for a number of reasons: first, they may influence decisions regarding pesticide use; second, if these perceptions differ from expert opinion, it is useful to know why and whether these lead farmers to take more risks than they realize; third, they may influence the methods of protection used against pesticides; and last, technical advice given to farmers on pesticide use and crop protection may be inappropriate and irrelevant if it does not tally with their own view of pesticide health effects.

This chapter describes farmers' pesticide use, perceptions particularly about health hazards, pesticide management practices, and attitudes toward personal protective equipment (ppe). The general objective of this study is to investigate pesticide health effects as perceived by rice farmers, laborers, and their spouses and how these affect their welfare and decisions on pest control. Specifically, the study aims to provide possible answers to the following questions:

- Are farmers aware of being affected by pesticides and if so, how?
- How do farmers perceive pesticide hazards and the factors affecting them?



- What are farmers doing to avoid pesticide contamination and why?
- What factors affect farmers' valuation of pesticide health risks, and do these affect decisions on pesticide use?

### **3.1. The Study Sites and Data Collection Methods**

#### **3.1.1. *The Study Sites***

The study was conducted in the rice-producing provinces of Laguna and Nueva Ecija in the Philippines. Laguna is located in the Southern Luzon region, situated about 25 kilometers from Metro Manila. Rice is grown as a major crop. Total rice production was about 135,000 metric tons in 1992, giving a mean irrigated rice yield of 4.20 tons per hectare, one of the highest yields among the country's rice-producing provinces.

Nueva Ecija is located 150 kilometers north of Metro Manila in the Central Luzon region, the rice bowl of the Philippines. With its annual rice production amounting to an average of 800,000 metric tons for the last ten years, Nueva Ecija supplies most of the rice requirements of the metropolis. It has one of the biggest irrigated rice areas in the country, producing a mean yield of about 4.10 tons per hectare.

Laguna and Nueva Ecija farmers are considered wide adopters of modern rice production technologies such as the use of high-yielding varieties, chemical fertilizers, and pesticides. Their respective patterns of pesticide use are discussed in detail in Section 3.2.

#### **3.1.2. *Data Collection Methods***

**3.1.2.1. Sample Farmers.** Thirty-six farmers in five municipalities of Laguna-Calauan, Calamba, Cabuyao, Biñan, and Santa Rosa—were periodically monitored beginning in 1966 (the thirty-six samples was reduced to thirty-two in 1987). These farmers are part of a more comprehensive provincial survey started in 1966, which has been monitoring farm inputs and rice production over time. In the 1988 wet season (WS), a survey of these thirty-six farmers was conducted specifically to determine pesticide perceptions and safety practices.

In Nueva Ecija, a survey in the 1989 dry season (DS) on pesticide use was conducted on fifty-seven farmers and laborers randomly chosen from the villages of Lagare and Caalibangbangan in Cabanatuan City. These individuals were also monitored for health effects of pesticide use in 1990 (see Chapter 12

for details). Later in 1991, an additional random sample of 105 rice farmers and laborers from Lagare, Caalibangbangan, and Santa Arcadia (also of Cabanatuan City) were chosen from the barangay lists of residents. The main criterion used in selecting the respondents was farming experience: he is a farmer or had carried out some rice farming work during the past year. The 162 farmer and laborer respondents were interviewed in the dry and wet seasons of 1991 and 1992.

Diagnostic surveys, formal and informal interviews, field observation, and analytical games were used to gather information about farmers' pesticide use, perceptions on health effects, and pest management practices. Formal interviews dealt with the general rice farming system and farmers' pest control practices, while the other methods assessed farmer perception of pesticide hazards. A simulated market survey was also conducted to determine the respondents' willingness to pay for protective equipment, such as gloves and mask. Analytical games and simulated market surveys were conducted in Nueva Ecija only.

**3.1.2.2. Diagnostic Surveys.** Initially, informal semistructured interviews were conducted in 1989 to gather benchmark information on the general rice production system in the villages, giving particular attention to pesticide use patterns and problems associated with their use.

Group discussions were held separately with rice farmers and laborers to minimize domination of the discussions by one particular group. Participants were asked about problems in using pesticides in general, to avoid biased answers toward health effects if pesticides were not seen as a problem. Information gathered were then used as basis for designing the formal interviews conducted in the succeeding years.

**3.1.2.3. Formal and Informal Interviews.** In 1990 and 1991, structured questionnaires were used to collect information on rice farming systems and pesticide use and practices in Laguna and Nueva Ecija. Information on the number of years of pesticide use, method of pesticide application, and precautions taken was obtained from the respondents. Information on family illnesses and medical expenses, including those that may be related to pesticide use, was also gathered from each household, usually from the wife or from whoever was responsible for the general health care in the household.

**3.1.2.4. Field Observations.** Since formal interviews can be subjected to "interviewer and respondent" bias and to lack of precise response, a field observation survey of farmers, laborers, and their spraying practices was discreetly conducted. The subjects were not informed beforehand to avoid modifications in

Table 3.2. Description of Ranking Levels Used for Pesticide Ranking Game

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|                |                                                                                         |
|----------------|-----------------------------------------------------------------------------------------|
| Effectiveness: |                                                                                         |
| 1              | Very effective: 75–100% insects killed                                                  |
| 2              | Effective: 50–75% insects killed                                                        |
| 3              | Small effect only: < 50% insects killed                                                 |
| 4              | No effect                                                                               |
| 5              | Makes the insect problem worse                                                          |
| Hazard:        |                                                                                         |
| 1              | Extremely hazardous: likelihood of hospitalization or long-term illness                 |
| 2              | Moderately hazardous: likelihood of more than two days sick and need to see a doctor    |
| 3              | Slightly hazardous: likelihood of dizziness or vomiting or blurred vision or skin sores |
| 4              | Least hazardous: likelihood of some dizziness, tiredness, or headache                   |
| 5              | No effects                                                                              |

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pesticide-handling behavior; the field observation sample then depended on who was spraying at the time. Results of the field observation were a useful check on the reliability of the above questionnaire.

**3.1.2.5. Analytical Games.** Pesticide perceptions and health risks were assessed through a ranking game participated in by the farmers, laborers, and their spouses. The game was conducted only during the 1991 DS in Nueva Ecija.

All participants were individually shown a total of nineteen numbered color photos (cards) of pesticides commonly available in the area. The cards were shown one by one, and the names of the pesticides were read out to ensure that each participant knew what was there. They were asked which ones they recognized (but not necessarily used); the unfamiliar pesticides were removed and noted in the questionnaire. From the familiar cards, the respondents were asked which ones were thought generally effective in controlling pests, hence dividing the cards into two piles: “effective” and “ineffective.” The “ineffective” pile was removed, and the “effective” cards were ranked accordingly. Once the cards were ranked, the respondents were asked to describe how effective each pesticide was on a scale of one to five (Table 3.2). The scale ranged from very effective (rank 1) for killing 75 to 100 percent of the insects, to less effective (rank 2) for killing 50 to 75 percent, to making the insect problem worse (rank 5). If they wished, they could describe as many cards as they liked in one

category. Finally, they were asked their reasons for ranking a particular pesticide as the most effective.

A similar process was followed to rank the pesticides according to hazard. The participants were asked to select and rank cards of pesticides thought to be hazardous. Again, they were asked to describe the cards on a scale of one to five (Table 3.2), and to provide reasons for ranking a particular pesticide as the most hazardous. Pesticide hazard ranking ranged from extremely hazardous (rank 1) (causing long-term illness and hospitalization) to slightly hazardous (rank 3) (causing dizziness, vomiting, or blurred vision) to having no effects (rank 5).

**3.1.2.6. Simulated Market Survey.** Respondent attitude and use of personal protective equipment was assessed through a simulated market survey of the gloves and mask. At first, the equipment was lent to a subset of the original 162 respondents for use during the DS crop. It was collected at the end of the season, and the borrowers were asked for opinions about the equipment. Those who wished to keep the gloves could buy them at P 100.00 if he was a farmer and at P 50.00 if he was a laborer. Those who wished could buy the mask at P 250.00 if he was farmer and at P 100.00 if he was a laborer. The nonborrowers were also asked if they were willing to buy, and hence bid for, the equipment. Logit regressions were used to determine the factors affecting the farmers' and laborers' willingness to purchase either or both pieces of personal protective equipment.

## **3.2. Pesticide Use Profile of Rice Farmers<sup>1</sup>**

### **3.2.1. *Frequency of Pesticide Applications***

Pesticide application patterns by rice farmers have not reflected current pest situations. Even with no serious pest attacks, Laguna and Nueva Ecija farmers increasingly applied pesticides, particularly insecticides, over time. While frequency of application peaked in the mid-1980s, its average decreased in the early 1990s (Table 3.3). Possible reasons for this reduction may be increases in farmer awareness of pest thresholds or in host plant resistance. The variance of application frequency likewise decreased over time. Hence, in 1991, very few farmers were observed spraying more than six times, in contrast to earlier years. This implies that farmers are moving away from calendar spraying.

Herbicide use in both Laguna and Nueva Ecija has remained fairly constant over time with an average of one application. Molluscicide use started in the late 1980s by 45 percent of Nueva Ecija farmers and 14 percent of Laguna farmers. In the 1990s, more Nueva Ecija farmers are using molluscicides, especially in

Table 3.3. Frequency of Pesticide Application in Laguna (1966-1990) and Nueva Ecija (1979-1991)

| <i>Pesticide</i>  | <i>Number of Applications</i> | <i>LAGUNA</i>     |      |      |      |                   |      |
|-------------------|-------------------------------|-------------------|------|------|------|-------------------|------|
|                   |                               | <i>Wet Season</i> |      |      |      | <i>Dry Season</i> |      |
|                   |                               | 1966              | 1978 | 1988 | 1990 | 1988              | 1990 |
| Insecticide       | 0                             | 18                | 1    | 2    | 2    | 5                 | 5    |
|                   | 1                             | 14                | 18   | 8    | 11   | 6                 | 6    |
|                   | 2                             | 1                 | 11   | 9    | 9    | 8                 | 6    |
|                   | 3                             | 1                 | 3    | 4    | 2    | 5                 | 1    |
|                   | 4                             | 0                 | 1    | 5    | 3    | 3                 | 3    |
|                   | 5                             | 0                 | 0    | 1    | 1    | 0                 | 2    |
|                   | ≥ 6                           | 0                 | 0    | 4    | 1    | 2                 | 2    |
| Herbicide         | 0                             | 6                 | 3    | 3    | 0    | 8                 | 1    |
|                   | 1                             | 30                | 26   | 23   | 21   | 17                | 15   |
|                   | 2                             | 0                 | 5    | 5    | 5    | 3                 | 6    |
|                   | 3                             | 0                 | 0    | 1    | 1    | 1                 | 1    |
|                   | 4                             | 0                 | 0    | 1    | 1    | 0                 | 1    |
|                   | ≥ 5                           | 0                 | 0    | 0    | 1    | 0                 | 1    |
| Molluscicide      | 0                             | 36                | 34   | 28   | 22   | 25                | 14   |
|                   | 1                             | 0                 | 0    | 5    | 5    | 4                 | 7    |
|                   | 2                             | 0                 | 0    | 0    | 2    | 0                 | 4    |
| Total respondents |                               | 36                | 34   | 33   | 29   | 29                | 25   |

| <i>Pesticide</i>  | <i>Number of Applications</i> | <i>NUEVA ECIJA</i> |      |      |                   |      |      |
|-------------------|-------------------------------|--------------------|------|------|-------------------|------|------|
|                   |                               | <i>Wet Season</i>  |      |      | <i>Dry Season</i> |      |      |
|                   |                               | 1979               | 1985 | 1991 | 1979              | 1985 | 1991 |
| Insecticide       | 0                             | 28                 | 0    | 7    | 32                | 0    | 10   |
|                   | 1                             | 29                 | 6    | 33   | 32                | 12   | 15   |
|                   | 2                             | 38                 | 29   | 28   | 24                | 32   | 41   |
|                   | 3                             | 25                 | 24   | 14   | 26                | 38   | 19   |
|                   | 4                             | 13                 | 36   | 5    | 15                | 29   | 7    |
|                   | 5                             | 4                  | 16   | 6    | 7                 | 9    | 2    |
|                   | ≥ 6                           | 8                  | 32   | 0    | 7                 | 18   | 1    |
| Herbicide         | 0                             | 64                 | 9    | 10   | 42                | 9    | 4    |
|                   | 1                             | 67                 | 99   | 76   | 84                | 105  | 74   |
|                   | ≥ 2                           | 14                 | 35   | 7    | 19                | 24   | 18   |
| Molluscicide      | 0                             | 34                 | 0    | 66   | 25                | 0    | 65   |
|                   | 1                             | 0                  | 0    | 24   | 4                 | 0    | 28   |
|                   | ≥ 2                           | 0                  | 0    | 3    | 0                 | 0    | 2    |
| Total respondents |                               | 145                | 143  | 93   | 143               | 138  | 95   |

the WS, because of prevalent snail problem in flooded areas. Its average frequency of application has however remained constant at one.

### 3.2.2. *Quantity of Pesticide Use*

Rice farmers in Laguna and Nueva Ecija use more organochlorines and organophosphates than carbamates and pyrethroids. In Laguna, WS total insecticide use increased from 0.35 kg ai/ha in 1978 to 0.43 kg ai/ha in 1990 (Table 3.4). DS total insecticide use also increased from 0.41 to 0.48 kg ai/ha in 1988 and 1990, respectively. In Nueva Ecija, WS total insecticide use decreased from 1.07 kg ai/ha in 1979 to 0.50 kg ai/ha in 1991. Insecticide use for the DS likewise decreased from 1.29 kg ai/ha to 0.60 kg ai/ha in 1979 and 1991 respectively.

Farmers obtain their knowledge about pesticide dosage from government technicians, pesticide salespeople, pesticide labels, and other farmers (Table 3.5). Proper training about correct dosages is then imperative for government technicians because industry representatives may tend to convey a message of higher dosages and frequent application to increase their sales. Safety instructions provided on pesticide labels may also be too nebulous for farmers to understand, causing the use of incorrect dosages. In addition, farmers may experiment on their own and may deliberately underdose.

Compared to other crops, insecticide use on rice is low (Table 3.6) and will likely remain low because so much more research on host plant resistance is being done on rice than on other crops. Also insecticide use on rice neither enhances rice grain quality nor improves yields in the absence of pest pressures. In contrast, the use of fungicides, which do improve the appearance of high-valued fruits and vegetables, is likely to increase.

### 3.2.3. *Timing of Pesticide Applications*

Factors critical to farmers' timing of pesticide applications include presence of pests, perceived intensity of infestation, transplanting date, and other factors such as fertilizer application dates and neighbors' recommendations (Table 3.7). Sixty-nine percent of Laguna farmers cited presence of pest as a major application criteria; 66 percent sprayed because of other factors. Fifty-eight percent of Nueva Ecija farmers sprayed when pest infestation is considered heavy; about 42 percent sprayed whenever pests are present, irrespective of pest density. Other criteria mentioned by respondents such as date of transplanting and date of fertilization were reminiscent of the recommended calendar spray schedules or complete protection treatments.

Table 3.4. Insecticide Use of Laguna Farmers (1978-1990) and Nueva Ecija Farmers (1979-1991)

|                               | LAGUNA      |             |             |             |             |             |
|-------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Chemical Compound<br>kg ai/ha | Wet Season  |             |             | Dry Season  |             |             |
|                               | 1978        | 1988        | 1990        | 1988        | 1990        |             |
| Organochlorines:              |             |             |             |             |             |             |
| Mean                          | 0.34        | 0.42        | 0.49        | 0.34        | 0.54        |             |
| Range                         | (.06-.73)   | (.07-.97)   | (.14-1.37)  | (.12-.98)   | (.13-1.53)  |             |
| Organophosphates:             |             |             |             |             |             |             |
| Mean                          | 0.39        | 0.49        | 0.47        | 0.57        | 0.63        |             |
| Range                         | (.07-1.17)  | (.08-1.46)  | (.19-1.34)  | (.06-1.40)  | (0.1-2.08)  |             |
| Carbamates:                   |             |             |             |             |             |             |
| Mean                          | 0.35        | 0.36        | 0.58        | 0.38        | 0.53        |             |
| Range                         | (.09-.79)   | (.08-.71)   | (.23-1.47)  | (.13-1.004) | (.13-1.23)  |             |
| Pyrethroids:                  |             |             |             |             |             |             |
| Mean                          |             | 0.16        | 0.10        | 0.11        | 0.05        |             |
| Range                         |             | (.09-.21)   | (04-.14)    | (.08-.14)   | (.002-.10)  |             |
| Total:                        |             |             |             |             |             |             |
| Mean                          | 0.35        | 0.40        | 0.43        | 0.41        | 0.48        |             |
| Range                         | (0-1.17)    | (.07-1.46)  | (0-1.47)    | (.06-1.47)  | (.002-2.08) |             |
|                               | NUEVA ECIJA |             |             |             |             |             |
| Chemical Compound<br>kg ai/ha | Wet Season  |             |             | Dry Season  |             |             |
|                               | 1979        | 1985        | 1991        | 1979        | 1985        | 1991        |
| Organochlorines:              |             |             |             |             |             |             |
| Mean                          | 0.33        | 0.55        | 0.43        | 0.84        | 0.43        | 0.53        |
| Range                         | (.01-1.24)  | (.07-1.60)  | (.18-1.05)  | (.09-4.42)  | (.12-.95)   | (.11-2.45)  |
| Organophosphates:             |             |             |             |             |             |             |
| Mean                          | 0.67        | 0.66        | 0.43        | 0.85        | 0.88        | 0.47        |
| Range                         | (.06-2.98)  | (.06-6.02)  | (.07-1.74)  | (.13-7.80)  | (.10-8.62)  | (.05-2.88)  |
| Carbamates:                   |             |             |             |             |             |             |
| Mean                          | 0.85        | 0.60        | 0.39        | 0.81        | 0.50        | 0.36        |
| Range                         | (.02-5.13)  | (04-2.62)   | (.007-1.13) | (.01-6.80)  | (.03-2.33)  | (.03-.70)   |
| Pyrethroids:                  |             |             |             |             |             |             |
| Mean                          |             | 0.65        | 0.04        |             | 0.13        | 0.07        |
| Range                         |             | (.005-.41)  | (.008-.17)  |             | (.008-1.00) | (.03-.70)   |
| Total:                        |             |             |             |             |             |             |
| Mean                          | 1.07        | 0.87        | 0.50        | 1.29        | 0.92        | 0.60        |
| Range                         | (.14-5.40)  | (.005-9.09) | (.008-1.88) | (.03-7.8)   | (.03-8.71)  | (.008-2.95) |

Table 3.5. Sources of Rice Farmers' Knowledge Regarding Rates of Pesticide Application, Laguna and Nueva Ecija (1988 wet season)

| <i>Source</i>          | <i>Laguna</i> |                | <i>Nueva Ecija</i> |                |
|------------------------|---------------|----------------|--------------------|----------------|
|                        | <i>Number</i> | <i>Percent</i> | <i>Number</i>      | <i>Percent</i> |
| Government technicians | 13            | 41             | 39                 | 65             |
| Pesticide labels       | 17            | 53             | 16                 | 27             |
| Fellow farmers         | 1             | 3              | 13                 | 22             |
| Pesticide salesmen     | 2             | 6              | 9                  | 15             |
| Others                 | 16            | 50             | 11                 | 18             |
| Total                  | 32            | 100            | 60                 | 100            |

Note: Multiple responses. Others include radio advertisements, store dealers, seminars, and actual experiences.

Table 3.6. Mean Pesticide Usage (kg ai/ha), Various Crops, Philippines<sup>a</sup>

| <i>Crop</i>        | <i>Usage (kg ai/ha)</i> |                   |                   |                           | <i>Total</i> |
|--------------------|-------------------------|-------------------|-------------------|---------------------------|--------------|
|                    | <i>Insecticides</i>     | <i>Herbicides</i> | <i>Fungicides</i> | <i>Others<sup>b</sup></i> |              |
| Vegetables:        |                         |                   |                   |                           |              |
| Cabbage            | 2.96                    | 2.00              | 2.08              |                           | 7.04         |
| Onion              | 1.51                    | 0.23              | 2.00              |                           |              |
| Fruit:             |                         |                   |                   |                           |              |
| Mango <sup>c</sup> | 0.32                    | 0.01              | 0.51              | 1.26                      | 2.10         |
| Banana             | 0.16                    | 0.31              | 1.31              |                           | 1.77         |
| Pineapple          | 0.30                    | 3.29              | 0.25              |                           | 3.85         |
| Grain:             |                         |                   |                   |                           |              |
| Rice               | 0.51                    | 0.52              | 0.24              | 0.31                      | 1.57         |
| Maize              | 0.47                    | 0.52              | 0.18              |                           | 1.16         |
| Others:            |                         |                   |                   |                           |              |
| Tobacco            | 0.37                    |                   | 0.05              |                           | 0.43         |

Source: Rola, Chupungco, Corcolon, and Hernandez (1992).

a. These are the results of a survey of 460 farmer respondents in selected Philippine provinces.

b. Includes molluscicides, rodenticides, and flower inducers.

c. In kg ai/tree.



Table 3.7. Factors That Farmers Consider in Timing of Insecticide Application, Laguna, 1988 WS and Nueva Ecija, 1989 DS

| <i>Source</i>              | <i>Laguna</i> |                | <i>Nueva Ecija</i> |                |
|----------------------------|---------------|----------------|--------------------|----------------|
|                            | <i>Number</i> | <i>Percent</i> | <i>Number</i>      | <i>Percent</i> |
| Presence of pest           | 22            | 69             | 25                 | 42             |
| Degree of pest infestation | 11            | 34             | 35                 | 58             |
| Date of transplanting      | 5             | 16             | 13                 | 22             |
| Others                     | 21            | 66             | 14                 | 23             |
| Total respondents          | 32            | 100            | 60                 | 100            |

Note: Multiple responses. Total responses per item over total respondents, Others include date of fertilizer application, neighbors' recommendation, and spraying even without pest or damage.

### 3.2.4. *Types of Pesticides Used by Rice Farmers*

Filipino rice farmers use mostly category I and II insecticides, which WHO respectively classifies as extremely and moderately hazardous (Tables 3.8 and 3.9). These categories include organochlorines (OC) and organophosphates (OP). Herbicides used are mostly under category IV, with a few under category II, especially those used during the 1960s and 1970s. Category IV pesticides are those that are unlikely to present acute hazard in normal use.

Among the OCs, endrin and endosulfan were most widely used in 1979 in the Philippines. Endrin however was banned in the early 1980s and was totally out of use in 1991. On the other hand, the use of endosulfan as a molluscicide is increasing because it effectively controls golden snail on rice. Because endosulfan is registered only as an insecticide, this misuse by farmers became grounds for regulation and a proposal to prohibit endosulfan importation is under a close review by Philippine pesticide policymakers.

Filipino farmers use more organophosphates (OPs) than organochlorines (OCs). OPs such as methyl parathion, monocrotophos, and azinphos-ethyl are cheaper, widely available, and known for wide-spectrum toxicity. These chemicals, popular in the Philippines, have been banned or severely restricted in the United States (see Table 3.1). The Philippine government announced a ban on these three chemicals only in 1993.

Rich farmers also use carbamates and pyrethroids, which are classified in the moderately hazardous category. Current retail prices of pyrethroids especially are however almost twice as high as those for OCs and OPs, hence discouraging farmer use (Table 3.10). Policies geared toward making pyrethroids competitive with OPs and OCs could mitigate farmer health risks associated with pesticide use. Carbamate prices are comparable with those of OCs and OPs.

Table 3.8. Types of Pesticides Applied by Season, Laguna, 1966–1990

| Chemical                        | Percentage of Farmers Reporting |       |       |       |       |       |       |
|---------------------------------|---------------------------------|-------|-------|-------|-------|-------|-------|
|                                 | Category                        | 66WS  | 78WS  | 88DS  | 88WS  | 90DS  | 90WS  |
| A. Herbicide                    |                                 |       |       |       |       |       |       |
| Phenoxy:                        |                                 |       |       |       |       |       |       |
| 2,4-D                           | II                              | 88.24 | 32.35 | 5.88  | 15.15 | 7.14  | 17.24 |
| Acetamide:                      |                                 |       |       |       |       |       |       |
| Butachlor                       | IV                              | 0     | 58.82 | 55.88 | 84.85 | 82.14 | 89.66 |
| B. Insecticide                  |                                 |       |       |       |       |       |       |
| Organochlorine:                 |                                 |       |       |       |       |       |       |
| Endrin                          | I                               | 29.41 | 5.88  | 0     | 0     | 0     | 0     |
| Endosulfan                      | II                              | 0     | 17.65 | 38.24 | 36.36 | 25.00 | 41.38 |
| Organophosphorus:               |                                 |       |       |       |       |       |       |
| Methyl parathion                | I                               | 17.65 | 23.53 | 5.88  | 9.09  | 3.57  | 6.90  |
| Malathion                       | III                             | 2.94  | 0     | 0     | 3.03  | 0     | 0     |
| Diazinon                        | II                              | 0     | 0     | 8.82  | 0     | 0     | 0     |
| Monocrotophos                   | I                               | 0     | 17.65 | 35.29 | 45.45 | 28.57 | 24.14 |
| Carbamates:                     |                                 |       |       |       |       |       |       |
| Carbaryl                        | II                              | 0     | 5.88  | 5.88  | 3.03  | 0     | 0     |
| Isoproc carb                    | II                              | 0     | 2.94  | 2.94  | 3.03  | 0     | 3.45  |
| BPMC                            | II                              | 0     | 11.76 | 0     | 0     | 3.57  | 0     |
| + chlorpyrifos                  | II                              | 0     | 32.35 | 20.59 | 39.39 | 28.57 | 37.93 |
| Carbofuran                      | I                               | 0     | 8.82  | 2.94  | 9.09  | 14.29 | 6.90  |
| Methomyl                        | I                               | 0     | 0     | 8.82  | 3.03  | 7.14  | 3.45  |
| Pyrethroid:                     |                                 |       |       |       |       |       |       |
| Cypermethrin                    | II                              | 0     | 0     | 2.94  | 0     | 3.57  | 6.90  |
| Cypermethrin<br>+ monocrotophos | II                              | 0     | 0     | 5.88  | 15.15 | 7.14  | 13.79 |
| C. Molluscicide                 |                                 |       |       |       |       |       |       |
| Organotin:                      |                                 |       |       |       |       |       |       |
| Fentin acetate                  | II                              | 0     | 0     | 8.82  | 9.09  | 7.14  | 3.45  |
| Fentin chloride                 | II                              | 0     | 0     | 2.94  | 6.06  | 32.14 | 17.24 |

Table 3.9.    Types of Pesticide Applied by Season, Nueva Ecija, 1979-1991

| Chemical                        | Category | Percentage of Farmers Reporting |       |       |       |       |       |       |
|---------------------------------|----------|---------------------------------|-------|-------|-------|-------|-------|-------|
|                                 |          | 79DS                            | 79WS  | 85DS  | 85WS  | 88DS  | 89DS  | 91WS  |
| A. Herbicide                    |          |                                 |       |       |       |       |       |       |
| Phenoxy:                        |          |                                 |       |       |       |       |       |       |
| 2,4-D                           | II       | 4.50                            | 5.98  | 2.90  | 0.70  | 0.74  | 1.67  | 0     |
| 2,4-D + butachlor               | II       | 0                               | 0     | 2.17  | 1.40  | 0.74  | 0     | 0     |
| 2,4-D + piperophos              | II       | 0                               | 0     | 15.94 | 19.58 | 10.29 | 6.67  | 5.26  |
| 2,4-D + thiobencarb             | II       | 0                               | 0     | 1.45  | 2.10  | 3.68  | 8.33  | 7.02  |
| Acetamide:                      |          |                                 |       |       |       |       |       |       |
| Butachlor                       | IV       | 88.29                           | 64.96 | 72.46 | 72.73 | 38.97 | 18.33 | 22.81 |
| Pretilachlor                    | IV       | 0                               | 0     | 0.72  | 0.70  | 43.38 | 85.00 | 70.18 |
| Thiocarbamate:                  |          |                                 |       |       |       |       |       |       |
| Thiobencarb                     | III.80   | 0.85                            | 5.07  | 2.80  | 5.88  | 11.57 | 17.54 |       |
| B. Insecticide                  |          |                                 |       |       |       |       |       |       |
| Organochlorine:                 |          |                                 |       |       |       |       |       |       |
| Endrin                          | I        | 9.91                            | 11.11 | 0     | 1.40  | 0     | 1.67  | 0     |
| Endosulfan                      | II       | 3.60                            | 5.96  | 8.70  | 4.20  | 8.82  | 30.00 | 22.81 |
| Organophosphorous:              |          |                                 |       |       |       |       |       |       |
| Methyl parathion                | I        | 8.11                            | 11.97 | 9.42  | 8.39  | 8.09  | 8.33  | 1.75  |
| Malathion                       | III      | 0.90                            | 0.85  | 0.72  | 0     | 0     | 1.67  | 0     |
| Diazinon                        | II       | 15.32                           | 9.40  | 2.90  | 0     | 2.94  | 1.67  | 0     |
| Monocrotophos                   | I        | 33.33                           | 35.90 | 55.07 | 59.44 | 44.85 | 51.67 | 45.61 |
| Azinphos-ethyl                  | I        | 11.71                           | 6.84  | 3.62  | 4.20  | 2.21  | 0     | 3.51  |
| Carbamates:                     |          |                                 |       |       |       |       |       |       |
| Carbaryl                        | II       | 3.60                            | 3.42  | 0.72  | 0.70  | 2.21  | 5.00  | 5.26  |
| Isoproc carb                    | II       | 36.04                           | 26.50 | 10.14 | 10.49 | 34.56 | 45.00 | 29.82 |
| Isoproc carb + lindane          | II       | 2.70                            | 4.27  | 32.61 | 26.67 | 0     | 0     | 0     |
| BPMC                            | II       | 1.80                            | 1.71  | 6.52  | 4.90  | 2.94  | 5.00  | 1.75  |
| BPMC + chlorpyrifos             | II       | 54.05                           | 53.85 | 26.09 | 39.86 | 27.94 | 31.67 | 19.30 |
| BPMC + phenthoate               | II       | 0                               | 0     | 2.90  | 4.20  | 0.74  | 0     | 0     |
| Carbofuran                      | I        | 9.01                            | 9.40  | 1.45  | 2.80  | 5.88  | 1.67  | 0     |
| Methomyl                        | I        | 11.71                           | 9.40  | 2.90  | 3.50  | 0.74  | 1.67  | 1.75  |
| Pyrethroid                      |          |                                 |       |       |       |       |       |       |
| Deltamethrin                    | II       | 0                               | 0     | 0     | 0     | 0.74  | 1.67  | 1.75  |
| Cypermethrin                    | II       | 0                               | 0     | 20.29 | 23.78 | 25.00 | 10.00 | 10.53 |
| Cypermethrin<br>+ monocrotophos | II       | 0                               | 0     | 7.97  | 6.29  | 16.91 | 6.67  | 3.51  |
| C. Molluscicide                 |          |                                 |       |       |       |       |       |       |
| Organotin:                      |          |                                 |       |       |       |       |       |       |
| Fentin acetate                  | II       | -                               | -     | -     | -     | -     | 5.00  | 12.28 |
| Fentin chloride                 | V        | -                               | -     | -     | -     | -     | 18.33 | 5.26  |

Table 3.10. Average Retail Prices of Chemicals (P/liter or kg), Urea (P/kg), and Rough Rice (P/kg), Nueva Ecija, Philippines (at 1979 Prices)

|                 | <i>Dry Season</i> |             | <i>Wet Season</i> |             |
|-----------------|-------------------|-------------|-------------------|-------------|
|                 | <i>1979</i>       | <i>1991</i> | <i>1979</i>       | <i>1991</i> |
| Chemical:       |                   |             |                   |             |
| Organochlorine  | 41                | 54.75       | 42                | 50.88       |
| Organophosphate | 47                | 60.86       | 49                | 52.51       |
| Carbamate       | 51                | 57.60       | 48                | 55.57       |
| Pyrethroid      | nd <sup>a</sup>   | 84.47       | nd                | 92.81       |
| Urea            | 1.91              | 1.07        | 1.91              | 1.07        |
| Rough rice      | 1.05              | 0.92        | 1.05              | 0.92        |

a. nd = no data, pyrethroids were not in the market in 1979.

### 3.3. Pesticide Safety and Storage Practices

Acute pesticide poisonings in Philippine rice farm households can be traced for several reasons to unsafe handling, storage, and disposal practices. First, although some farmers may be aware of pesticide hazards, adequate storage and disposal systems can hardly be afforded. Some farmers are also unaware of the consequences of mishandling chemicals. Hence, farmer training on proper pesticide handling, storage, and disposal could minimize unnecessary exposure to the chemicals.

#### 3.3.1. Pesticide Application

All respondents use a metal knapsack sprayer, both for rice and vegetables. The average age of the sprayers is 12.8 years. For small areas such as seedbeds, the farmers sometimes mix the chemicals at home. However, for a whole ricefield, he normally takes the pesticide bottles and mixes the chemicals with water from the canal. Spraying is usually done in the early morning and again in the late afternoon if necessary. One person can cover at least one hectare in a day and occasionally as much as two hectares. Usually, the sprayman works on his own, but for a large area (three hectares or more), two sprayers may work together.

There are several characteristics of this spray technology that are important with regard to pesticide exposure. The applicator sprays in front of him, so he tends to walk into the cloud of spray. Sprayers may leak, so the chemical drips onto the applicator's back or from the hose onto his hands. Each sprayerload has to be prepared by mixing the concentrated pesticide with water, presenting

Table 3.11. Farmer Pesticide Handling Practices and Kinds of Protective Cover, Laguna 1988 WS and Nueva Ecija 1989 DS, Philippines

| <i>Variable</i>                          | <i>Laguna</i> |                | <i>Nueva Ecija</i> |                |
|------------------------------------------|---------------|----------------|--------------------|----------------|
|                                          | <i>Number</i> | <i>Percent</i> | <i>Number</i>      | <i>Percent</i> |
| Direction of spraying:                   |               |                |                    |                |
| With the wind                            | 13            | 41             | 40                 | 63.5           |
| Against the wind                         | 0             |                | 11                 | 17.5           |
| Perpendicular                            | 19            | 59             | 12                 | 19.0           |
| Kinds of protective cover:               |               |                |                    |                |
| No protective clothing <sup>a</sup>      | 2             | 6              | 1                  | 1.6            |
| Partial protective clothing <sup>b</sup> | 30            | 94             | 57                 | 95.0           |
| Full protective clothing <sup>c</sup>    | 0             |                | 2                  | 3.3            |

a. Short pants and teeshirt.

b. Short pants/long sleeves or teeshirt/long pants.

c. Long pants, long sleeves, mask, and gloves.

associated risks of contamination. Overall, the applicator using a knapsack sprayer faces a higher level of exposure (particularly dermal) compared with other methods of application. A study of applicators using paraquat illustrates this point, where average dermal exposure was more than 100 times that with a vehicle mounted or aerial spraying (WHO, 1984, cited in Conway and Pretty, 1991).

The knapsack sprayer is heavy (over 20 kg when full) and involves considerable effort to use, especially in conditions of walking through a waterlogged ricefield. The applicator then becomes hot and tired while spraying, thus increasing his susceptibility to pesticide exposure.

### 3.3.2. *Handling and Reentry Intervals*

Most farmers in Laguna and Nueva Ecija spray chemicals with the wind. However, one in five still sprays against the wind (Table 3.11). Majority of the respondents also use partial protective clothing, but very few wear masks. This increases the probability of poisoning through chemical inhalation. The more frequent the application, the higher their exposure.

Reentry interval is the period after spraying that allows safe entry into the field. It is based on the time required for chemical to dissipate in the environment. Most OPs and OCs need an interval of at least seventy-two hours. In contrast, 72 and 75 percent of Laguna and Nueva Ecija farmers, respectively, return to the field within forty-eight hours to see if the spray has taken effect (Table 3.12). It is also suspected that only a few manual weeders (traditionally

Table 3.12. Farmer Reentry Periods, Laguna 1988 Wet Season and Nueva Ecija, 1989 DS, Philippines

| <i>Number of Hours</i> | <i>Laguna</i> |                | <i>Nueva Ecija</i> |                |
|------------------------|---------------|----------------|--------------------|----------------|
|                        | <i>Number</i> | <i>Percent</i> | <i>Number</i>      | <i>Percent</i> |
| Less than 48 hours     | 23            | 72             | 45                 | 75             |
| From 48 to 72 hours    | 5             | 16             | 8                  | 13             |
| More than 72 hours     | 4             | 12             | 7                  | 12             |

Note: Recommended reentry period is seventy-two hours for category I chemicals and forty-eight hours for other categories. Reentry period is dissipation time for chemicals and tells farmers when it is safe to reenter newly sprayed fields.

women) know about reentry interval requirements. In any case, no danger signs are posted on newly sprayed fields. Thus, weeders, children, and other household members in or near newly sprayed fields are directly exposed to pesticides.

### 3.3.3. *Pesticide Storage and Disposal Practices*

Majority of the farmers in Laguna and Nueva Ecija have extremely unsafe pesticide storage and disposal practices, indicating high probability of accidental exposure to the chemicals as well (Table 3.13). Only 35 percent and 13 percent of Laguna and Nueva Ecija respondents, respectively, mentioned safe storage practice. Any practice except placing dangerous chemicals in a locked cabinet outside the house is considered unsafe. Most farmers' houses do not have cabinets for such purpose; an improvised cabinet under the house flooring is a popular pesticide storage space. This, however, is especially accessible to children.

Disposal of pesticide bottles was also unsafely done. Sixty-nine percent of Laguna respondents threw them into the paddy ecosystem. The practice indicates possibilities of accidental exposure for the farm family and animals and of chemical seepage to the groundwater table. In Nueva Ecija, a majority (72 percent) of the respondents sold their empty pesticide containers. One common mode of disposal is piling empty pesticide bottles in an unfenced place in the farm. Again, the practice remains unsafe since children could take containers from this garbage heap.

### 3.3.4. *Sprayer Use and Maintenance*

Knapsack sprayers with a sixteen-liter capacity are widely used by rice farmers in Laguna and Nueva Ecija (Table 3.14). While most respondents own a sprayer,

Table 3.13. Pesticide Storage and Disposal of Empty Containers

| <i>Item</i>                                                            | <i>Laguna</i> |                | <i>Nueva Ecija</i> |                |
|------------------------------------------------------------------------|---------------|----------------|--------------------|----------------|
|                                                                        | <i>Number</i> | <i>Percent</i> | <i>Number</i>      | <i>Percent</i> |
| Pesticide storage after procurement:                                   |               |                |                    |                |
| Safe storage practices                                                 | 11            | 34.38          | 8                  | 13             |
| Unsafe storage practices                                               | 21            | 65.62          | 52                 | 87             |
| Disposal of empty pesticide bottles:                                   |               |                |                    |                |
| Sold                                                                   | 2             | 6.25           | 43                 | 72             |
| Disposed in the paddy ecosystem                                        | 22            | 68.75          | 4                  | 7              |
| Sold and disposed                                                      | 8             | 25.00          | 3                  | 5              |
| Pile and sold                                                          | 0             |                | 10                 | 16             |
| Return the cover of the empty pesticide bottles before disposing them: |               |                |                    |                |
| Yes                                                                    | 25            | 78.12          | 50                 | 83             |
| No                                                                     | 7             | 21.88          | 10                 | 17             |

Table 3.14. Sprayer Use and Maintenance

| <i>Item</i>                             | <i>Laguna</i> |                | <i>Nueva Ecija</i> |                |
|-----------------------------------------|---------------|----------------|--------------------|----------------|
|                                         | <i>Number</i> | <i>Percent</i> | <i>Number</i>      | <i>Percent</i> |
| Type of sprayer used:                   |               |                |                    |                |
| Knapsack sprayer                        | 32            | 100            | 59                 | 98             |
| Automatic sprayer                       |               |                | 1                  | 2              |
| Capacity of sprayer used (modal)        | 16 liters     |                | 16 liters          |                |
| Own a sprayer?                          |               |                |                    |                |
| Yes                                     | 24            | 75.00          | 50                 | 83             |
| No                                      | 8             | 25.00          | 10                 | 17             |
| Average number of sprayers owned        | 1.54          | 1.16           |                    |                |
| Wash sprayer after spraying:            |               |                |                    |                |
| Yes                                     | 31            | 96.88          | 50                 | 83             |
| No                                      | 1             | 3.12           | 10                 | 17             |
| Disposal of wash water used:            |               |                |                    |                |
| In the irrigation canal                 | 16            | 51.61          | 36                 | 72             |
| In the paddy field                      | 11            | 35.48          | 12                 | 24             |
| In the irrigation canal and paddy field | 4             | 12.90          | 1                  | 2              |
| Others                                  | 0             |                | 1                  | 2              |

sprayer maintenance appears to be a minor concern. For one, sprayer leakage is common, but farmers opt to do nothing about it. This creates no demand for sprayer repair shops.

About 97 and 83 percent of Laguna and Nueva Ecija respondents, respectively, wash their sprayers after use. Wash water is dumped in the irrigation canal or in the paddy field. The practice possibly contributes pesticide pollutants in the paddy runoff, which in turn poisons microorganisms in the paddy ecosystem and in surface water systems. In addition, contaminated irrigation water could also come into contact with the human skin, leading to pesticide poisoning.

### **3.4. Food and Feed Obtained from the Paddy Ecosystem**

Thirty-four percent of Laguna and 63 percent of Nueva Ecija respondents reported getting food other than rice from the paddy ecosystem (Table 3.15). Vegetables, root crops, frogs, and fish are the most common food taken. Surprisingly, farmers with a high intensity of pesticide use (those making more than three applications per season) were taking as much food out of the paddy as farmers with low levels of pesticide use.

In addition to directly consuming contaminated products, farmers also sell animal products that may have been contaminated by pesticides ingested while feeding in the paddy ecosystem. Ninety-one and 88 percent of Laguna and Nueva Ecija farmers reported getting feed from the paddy ecosystem. Feed commodities obtained include rice grains and other by-products, “kangkong” (*Ipomoea aquatica*), common grass, and snails. Chicken, ducks, and ruminants were the most common feed recipients.

### **3.5. Incidence of Insecticide Poisoning Among Rice Farm Households**

The assessment of pesticide toxicity is usually based on a variety of laboratory tests and tests on selected organisms in the field. The main parameter normally used by WHO to rank the different pesticides based on toxicity is  $LD_{50}$ <sup>2</sup> (WHO, 1990a). Pesticides are divided into four major hazard groups: category I, extremely hazardous; II, moderately hazardous; III, slightly hazardous; and IV, least hazardous or unlikely to present acute hazard under normal use (Table 3.16). Statistics of human poisonings correlate reasonably well with these toxicity ratings (Levine and Davies, 1982).



Table 3.15. Farmers Reporting on the Food and Feed Taken from the Paddy Ecosystem

| <i>Item</i>            | <i>Laguna</i> |                | <i>Nueva Ecija</i> |                |
|------------------------|---------------|----------------|--------------------|----------------|
|                        | <i>Number</i> | <i>Percent</i> | <i>Number</i>      | <i>Percent</i> |
| Farmers reporting      | 11            | 34.38          | 38                 | 63.33          |
| Food commodities:      |               |                |                    |                |
| Vegetable and rootcrop | 6             | 54.54          | 21                 | 55.26          |
| Fish                   | 4             | 36.36          | 16                 | 42.11          |
| Frogs                  | 5             | 45.45          | 20                 | 52.63          |
| Snails:                |               |                |                    |                |
| Golden                 | 0             |                | 1                  | 2.63           |
| Native                 | 1             | 9.09           | 3                  | 7.89           |
| Birds                  | 1             | 9.09           | 7                  | 18.42          |
| Rats                   | 0             |                | 9                  | 23.68          |
| Crabs                  | 0             |                | 3                  | 7.89           |
| Farmers reporting      | 29            | 90.62          | 53                 | 88.33          |
| Feed commodities:      |               |                |                    |                |
| Palay                  | 10            | 34.48          | 40                 | 75.47          |
| Rice bran              | 18            | 62.07          | 33                 | 62.26          |
| Cooked rice            | 1             | 3.45           | 7                  | 13.21          |
| “Kangkong”             | 2             | 6.90           | 16                 | 30.19          |
| Grass                  | 8             | 27.59          | 22                 | 41.51          |
| Rice straw             | 0             |                | 2                  | 3.77           |
| Snails                 | 0             |                | 6                  | 11.32          |

The hazards to humans of pesticides, however, do not only depend on its toxicity but also on the type and mode of exposure and on the health status of the individual affected (WHO, 1990b; Davies, Freed, and Whittemore, 1982).

### 3.5.1. Type and Mode of Exposure

The type of exposure can vary from extreme cases of intentional pesticide poisoning (when one large dose is ingested) to occasional, low-level dosages from pesticide residues in food or water. Of particular concern in this study is the long-term, unintentional, occupational exposure to pesticides of the farming community. Most at risk are those who are frequently mixing and spraying

Table 3.16. Classification of Pesticides According to Degree of Hazard to Human Beings<sup>a</sup>

| <i>Hazard Class</i> |                                                   | <i>LD<sub>50</sub> (rat) (mg/kg of body weight)<sup>b</sup></i> |               |               |               |
|---------------------|---------------------------------------------------|-----------------------------------------------------------------|---------------|---------------|---------------|
|                     |                                                   | <i>Oral</i>                                                     |               | <i>Dermal</i> |               |
|                     |                                                   | <i>Solid</i>                                                    | <i>Liquid</i> | <i>Solid</i>  | <i>Liquid</i> |
| Ia                  | Extremely hazardous                               | I 5                                                             | I 20          | £ 10          | £ 40          |
| Ib                  | Highly hazardous                                  | 5–50                                                            | 20–200        | 10–100        | 40–400        |
| II                  | Moderately hazardous                              | 50–500                                                          | 200–2000      | 100–1000      | 400–4000      |
| III                 | Slightly hazardous <sup>d</sup>                   | > 500                                                           | > 200         | > 1000        | > 4000        |
| IV                  | Unlikely to present acute hazard under normal use | > 2000                                                          | > 3000        |               |               |

Source: The WHO recommended classification of pesticides by hazard and guidelines to classification 1988–1989.

a. Classification is based on acute oral and dermal toxicity to the rat. However, classification of any compound can be adjusted if the acute hazard to man differs from that indicated by the LD<sub>50</sub> assessments alone.

b. LD<sub>50</sub> is a statistical estimate of the number of mg of toxicant per kg of body weight required to kill 50 percent of a large population of test animals.

c. Solids and liquids refer to the physical state of the product or formulation being tested.

d. Although category III is open-ended, in addition, WHO lists pesticides where the acute hazard is so low as to be negligible.

pesticides over many years. People working in newly sprayed fields and family members in close proximity to spray equipment, contaminated clothes, and pesticide containers are also subject to some exposure. In addition, there may even be pesticide residues in rice and other food taken from the fields such as fish and frogs, and some contamination in the water supply.

Pesticides can enter the human body through skin absorption, inhalation, or ingestion. In general, toxic effects are most rapid after ingestion, then inhalation, then dermal exposure (Davies, Freed, and Whittemore, 1982).

Related to this is the hazard presented by the pesticide formulation itself. Most pesticides are sold in a variety of active ingredient concentrations. The lower the concentration, the less toxic it is likely to be. However, additives (the “inactive ingredients”) in the formulation can affect or alter the properties of the pesticide, such as changing absorption through the skin (Yoshida, 1989). They may also be toxic themselves. In addition, the type of formulation—whether granular or liquid—also influences the application method that will be followed and therefore affects the type and mode of exposure.

Table 3.17. Number of Poisoning Cases as Reported by Thirty-Two Farmers, Laguna 1988 WS and Sixty Farmers, Nueva Ecija, 1989 DS, Philippines

| <i>Symptoms</i>     | <i>Laguna</i> |                | <i>Nueva Ecija</i> |                |
|---------------------|---------------|----------------|--------------------|----------------|
|                     | <i>Number</i> | <i>Percent</i> | <i>Number</i>      | <i>Percent</i> |
| Headache, dizziness | 8             | 25             | 35                 | 69             |
| Vomiting            | 10            | 31             | 12                 | 24             |
| Unconsciousness     | 0             |                | 8                  | 16             |
| Stomach pain        | 4             | 13             | 5                  | 10             |
| Weakness            | 2             | 6              | 3                  | 6              |
| Others              | 11            | 34             | 3                  | 6              |
| Total victims       | 32            |                | 51                 |                |

Notes: Multiple responses. As reported by respondents. Cases reported per total victims.

### 3.5.2. *Health Status of the Individual*

Malnutrition and dehydration are likely to increase susceptibility to pesticide poisoning (WHO, 1990b). If the individual is hot and sweating, pesticide uptake is likely to be greater (Davies, Freed, and Whittemore, 1982). WHO (1990b) lists some factors influencing skin absorption of pesticides as follows: (1) skin characteristics such as presence of sores and abrasions, wetness, location, and vascularization; (2) environmental factors such as temperature and humidity; and (3) pesticide characteristics such as pH, physical state, and concentration of active ingredient.

Due to the use and unsafe handling of hazardous pesticides, a number of on-farm poisonings have been recorded in the Philippine national statistics. Of the 4,031 acute pesticide poisonings reported by government hospitals, 603 resulted in death from 1980 to 1987 (Castañeda and Rola, 1990). The number of poisonings is likely underestimated, since most cases do not reach the hospital, and rural health officers may not always correctly diagnose pesticide poisoning. For acute pesticide poisonings reported at the national level such as those mentioned above, death rates ranged from 13 to 21 percent. National data in the Philippines show that most pesticide poisonings were suicidal (64 percent), accidental (16 percent), and occupational (14 percent) (Castañeda and Rola, 1990). Acute pesticide poisoning cases involved 54 percent males and 46 percent females.

In this study, farmers reported cases of acute pesticide poisoning with symptoms such as headaches, dizziness, vomiting, and stomach pain among others (Table 3.17). A detailed health examination of the Laguna and Nueva Ecija sample farmers included a comprehensive physical examination, blood

cholinesterase determination, chest X-rays, and electrocardiograms (EKGs). Results of this study are reported in Chapter 12.

Rola (1989) found that about 50 percent of rice farmers in rainfed and irrigated rice lands claimed sickness due to pesticide use. The incidence of sickness, however, is higher among vegetable farmers, who are heavy users of pesticides. Vegetable farmers and tree farmers display patterns similar to those of rice farmers in pesticide safety, handling, disposal, and storage practices (Rola, Chupungco, Corcolon, and Hernandez, 1992). Because this wider population uses more pesticides than do rice farmers, a higher probability of poisoning cases is expected. However, compared to rice farmers, non-rice crop farmers have fewer nonchemical pest control alternatives (see Chapter 2).

While pesticides are in general considered a panacea for the farmers' pest concerns, their use however created another set of problems. Frequent application of highly toxic chemicals increases risks of health damage from chemical exposure. Current pesticide pricing and regulatory structure combined with inadequate storage, unsafe handling practices, too short reentry intervals, and inefficient sprayer maintenance expose not just the farmer-applicators but their whole households as well to an increased risk of chemical poisoning.

### **3.6. Farmer Perception of Pesticide Effectivity and Hazards**

#### **3.6.1. *Pesticide Effectivity Ranking***

When farmers, laborers, and spouses ranked insecticides in order of effectivity, the majority ranked monocrotophos, cypermethrin, and endosulfan the most effective, followed by chlorpyrifos + BPMC and isoprocarb (Table 3.18). When asked how effective these chemicals were, the respondents tended to assign high levels of effectivity, with, for example, 61 percent of those who knew monocrotophos and 67 percent of those who knew cypermethrin ranked them level 1—that is, providing 75 to 100 percent insect control (see Table 3.2). The average effectivity level for all these five chemicals ranged between levels 1 and 2—that is, providing more than 50 percent insect control. There were no major differences in ranking between farmers and laborers, men and women. Barely no respondent perceives an insecticide as ineffective or as causing more pest problems. These results then indicate that the respondents, especially the farmers, are not aware of the concept of pest resurgence and natural enemies. To them, insecticides are always a solution to, never a cause of, insect pest problems.

Table 3.18. Number of Respondents Reporting on the Effectivity Ranking and Levels of Five Commonly Known Insecticides (Farmers, Laborers, and Spouses from 162 Households, Nueva Ecija, 1991)

| <i>Chemical Name</i> | <i>Effectivity Rank</i> |          |          |          | <i>Total Responses</i> | <i>Average Rank</i> |
|----------------------|-------------------------|----------|----------|----------|------------------------|---------------------|
|                      | <i>1</i>                | <i>2</i> | <i>3</i> | <i>4</i> |                        |                     |
| Endosulfan           | 62                      | 65       | 52       | 41       | 220                    | 2.3                 |
| Monocrotophos        | 108                     | 73       | 42       | 29       | 252                    | 2.0                 |
| BPMC + chlorpyrifos  | 47                      | 60       | 66       | 68       | 221                    | 2.5                 |
| Cypermethrin         | 93                      | 40       | 36       | 27       | 196                    | 2.0                 |
| Isoprocab            | 52                      | 55       | 54       | 91       | 252                    | 2.7                 |

| <i>Chemical Name</i> | <i>Effectivity Level<sup>a</sup></i> |          |          |          | <i>Total Responses</i> | <i>Average Level</i> |
|----------------------|--------------------------------------|----------|----------|----------|------------------------|----------------------|
|                      | <i>1</i>                             | <i>2</i> | <i>3</i> | <i>4</i> |                        |                      |
| Endosulfan           | 108                                  | 89       | 23       | 0        | 220                    | 1.6                  |
| Monocrotophos        | 153                                  | 78       | 21       | 0        | 252                    | 1.5                  |
| BPMC + chlorpyrifos  | 96                                   | 92       | 32       | 1        | 221                    | 1.7                  |
| Cypermethrin         | 131                                  | 48       | 16       | 1        | 196                    | 1.4                  |
| Isoprocab            | 95                                   | 90       | 66       | 1        | 252                    | 1.9                  |

a. Level 1 = 75–100 percent insect control; Level 2 = 50–75 percent insect control; Level 3 = below 50 percent insect control; Level 4 = not effective; Level 5 = causes more pest problems (0 reporting).

### 3.6.2. Pesticide Hazard Ranking

Results of the ranking game showed that the respondents can differentiate pesticides in terms of hazard to human health. More than two-thirds of the respondents ranked some insecticides, half ranked some molluscicides and less than one-third ranked some herbicides as hazard level 1—that is, extremely hazardous (Table 3.19). On average, respondents associated insecticides and molluscicides with hazard levels between 3 and 2 (slightly to moderately hazardous)—that is, a short-term illness is possible and a doctor's help may be needed. Herbicides are associated with hazard levels between 4 and 3 (very minor to slightly hazardous), with a likelihood of dizziness, vomiting, blurred vision, or skin sores. Only one respondent considered insecticides as harmless; four considered molluscicides as harmless; 12 percent considered herbicides as completely safe.

The laborers gave hazard ranks slightly higher than that of the farmers; across both groups, those who had attended a training course ranked hazards higher than those who had not. Women were less familiar with the pesticides in general,

Table 3.19. Highest Hazard Level of Pesticides Assigned by Respondents in Ranking Game, Nueva Ecija, 1991

| <i>Hazard Level</i>  | <i>Number (Percent) Reporting</i> |                     |                  |
|----------------------|-----------------------------------|---------------------|------------------|
|                      | <i>Insecticide</i>                | <i>Molluscicide</i> | <i>Herbicide</i> |
| Extremely hazardous  | 230 (70%)                         | 108 (50%)           | 64 (28%)         |
| Moderately hazardous | 40 (12%)                          | 36 (17%)            | 32 (14%)         |
| Slightly hazardous   | 36 (11%)                          | 44 (20%)            | 60 (26%)         |
| Least hazardous      | 18 (6%)                           | 24 (11%)            | 44 (19%)         |
| No effects           | 1 (0%)                            | 4 (2%)              | 28 (12%)         |
| Total responses      | 327                               | 216                 | 228              |

Note: Extremely hazardous = likelihood of hospitalization or long-term illness; moderately hazardous = likelihood of more than two days sickness and need to see a doctor; slightly hazardous = likelihood of dizziness, vomiting, blurred vision, or skin sores; minor hazard = likelihood of some dizziness, tiredness, or headache.

although pesticide knowledge varied widely from nothing to very strong views on different chemicals. Despite making a limited distinction between pesticides, however, the women gave an average hazard ranking similar to that of the men.

There was a consistent pattern across farmers and laborers, men and women, over the relative hazard ranking of different insecticides. Among the five insecticides chosen by most respondents, monocrotophos and endosulfan were ranked highest in terms of hazard, followed by that of chlorpyrifos + BPMC, cypermethrin, and isoprocarb (Table 3.20). Hazard ranks given by respondents are significantly associated with hazard level. On average, endosulfan, monocrotophos were thought to be moderately hazardous (hazard level 2), chlorpyrifos + BPMC slightly to moderately hazardous, and cypermethrin and isoprocarb slightly hazardous (hazard level 3).

**3.6.2.1. Does the Respondents' Ranking Tally with the WHO Hazard Codes?** Both scientists and farmers believe that pesticides are hazardous. Farmers' perception of relative hazard, however, differs slightly from that of the scientists using WHO ranking. For one, farmers tend to rank category I and II chemicals together with minimal distinction between the two. On average, farmers associate these insecticides with being moderately hazardous.

In general, the respondents' ranking of pesticide hazard does not correspond with that of WHO, which, in turn, is shown by color codes on each bottle (Table 3.21). Only 8.9 percent of the farmers and laborers and 4.9 percent of the spouses gave rankings matching that of WHO (Table 3.22). Among those with safety training: a higher proportion ranked the hazards similarly to WHO, as

Table 3.20. Hazard Ranking and Hazard Levels of Five Commonly Known Insecticides by Respondents from 162 households, Nueva Ecija, 1991

| <i>Chemical Name</i> | <i>Hazard Rank</i> |          |          |          | <i>Total Responses</i> | <i>Average Rank</i> |
|----------------------|--------------------|----------|----------|----------|------------------------|---------------------|
|                      | <i>1</i>           | <i>2</i> | <i>3</i> | <i>4</i> |                        |                     |
| Endosulfan           | 108                | 64       | 34       | 14       | 220                    | 1.8                 |
| Monocrotophos        | 120                | 74       | 38       | 19       | 251 <sup>a</sup>       | 1.8                 |
| BPMC + chlorpyrifos  | 64                 | 87       | 49       | 21       | 221                    | 2.1                 |
| Cypermethrin         | 46                 | 55       | 43       | 52       | 196                    | 2.5                 |
| Isoprocab            | 28                 | 40       | 66       | 117      | 251                    | 3.1                 |

| <i>Chemical Name</i> | <i>Hazard Level<sup>b</sup></i> |          |          |          | <i>Total Responses</i> | <i>Average Level</i> |
|----------------------|---------------------------------|----------|----------|----------|------------------------|----------------------|
|                      | <i>1</i>                        | <i>2</i> | <i>3</i> | <i>4</i> |                        |                      |
| Endosulfan           | 93                              | 42       | 47       | 38       | 220                    | 2.1                  |
| Monocrotophos        | 112                             | 47       | 43       | 50       | 252                    | 2.1                  |
| BPMC + chlorpyrifos  | 58                              | 47       | 67       | 49       | 221                    | 2.5                  |
| Cypermethrin         | 37                              | 32       | 43       | 84       | 196                    | 2.9                  |
| Isoprocab            | 35                              | 21       | 47       | 148      | 251                    | 3.2                  |

a. One missing observation.

b. Level 1 = extremely hazardous; Level 2 = moderately hazardous; Level 3 = slightly hazardous; Level 4 = very minor effects.

Table 3.21. Color Coding on Pesticide Bottles in the Philippines

| <i>Color Code</i> | <i>Category of Formulation</i> | <i>WHO Category</i> | <i>Message on Color Band</i>                |
|-------------------|--------------------------------|---------------------|---------------------------------------------|
| Red               | I                              | Ia and Ib           | "Danger, poison" plus skull and cross bones |
| Yellow            | II                             | II                  | "Harmful" plus X                            |
| Blue              | III                            | III                 | "Caution"                                   |
| Green             | IV                             | -                   |                                             |

compared to those without training (20 percent of those trained compared with 2.9 percent of untrained). There was no significant difference between farmers and laborers in their hazard ranking. Even respondents who used the color codes as a basis for hazard ranking did not always match the WHO ranking.

On the other hand, the respondents are able to make a clear distinction if the insecticides are classified into two groups only—hazardous (WHO categories I and II) and less hazardous (WHO categories III and IV). The average hazard levels for these main groups are significantly different for all respondents (Table

Table 3.22. Results of Hazard Ranking Game, All Respondents, Nueva Ecija, 1991

|                              |                                                                                    | Total Number | Percent |
|------------------------------|------------------------------------------------------------------------------------|--------------|---------|
| <i>Farmers and laborers:</i> |                                                                                    |              |         |
| 1                            | Number interviewed                                                                 | 158          | 100     |
| 2a                           | Hazard ranking agreed with color code                                              | 14           | 8.9     |
| 2b                           | Hazard ranking agreed with color code except for lower categories (blue and green) | 14           | 8.9     |
| 2c                           | Participants chose too few pesticides to rank them                                 | 2            | 1.2     |
| 2d                           | Hazard ranking did not agree with color code                                       | 128          | 81      |
| 3                            | Color code mentioned as a reason for hazard ranking                                | 23           | 14.6    |
| <i>Spouses:</i>              |                                                                                    |              |         |
| 1                            | Number interviewed                                                                 | 143          | 100     |
| 2a                           | Hazard ranking agreed with color code                                              | 7            | 4.9     |
| 2b                           | Hazard ranking agreed with color code except for lower categories (blue and green) | 12           | 8.4     |
| 2c                           | Participants chose too few pesticides to rank them                                 | 3            | 2.1     |
| 2d                           | Hazard ranking did not agree with color code                                       | 121          | 84.6    |
| 3                            | Color code mentioned as a reason for hazard ranking                                | 6            | 4.2     |

3.23). It appears that category II pesticides seem as hazardous as category I to many respondents, and that category III and IV pesticides are properly recognized as less hazardous.

**3.6.2.2. What Factors Affect the Respondents' Pesticide Hazard Ranking?**

In general, a respondent's perception of pesticide hazard might be thought to be related to its perceived effectiveness against pests—that is, if it is strong enough to control pests, then it is hazardous. However, results of a comparison between the respondents' perceptions of pesticide effectiveness and hazard do not support this hypothesis. Only 17 farmers (20 percent), 8 laborers (11 percent), and 25 women (17 percent) gave pesticide hazard rankings consistent with effectivity



Table 3.23. Hazard Level of Category I and II Insecticides Versus Category III and IV Insecticides, by Members of 162 Households, Nueva Ecija, 1991

| <i>Average Hazard Level Category</i> | <i>Men</i>     |                 | <i>Women</i>   |                 |
|--------------------------------------|----------------|-----------------|----------------|-----------------|
|                                      | <i>Farmers</i> | <i>Laborers</i> | <i>Farmers</i> | <i>Laborers</i> |
| I and II                             | 2.59           | 2.56            | 2.99           | 3.00            |
| III and IV                           | 3.57           | 3.59            | 3.74           | 3.67            |

rankings. The average rank correlation was not significantly different from zero, implying that respondents do not necessarily associate hazardous pesticides with better pest control. What factors then affect the respondents' pesticide hazard ranking? Why are their hazard rankings different from that of WHO?

A strong odor is perceived as the main indicator of pesticide (especially of insecticides and herbicides) among farmers (Table 3.24). Category I pesticides such as methyl parathion were often ranked below category II pesticides, which have a stronger smell. Except for fentin chloride molluscicides (which damage finger- and toenails) and, to a lesser extent, some of the acetamide herbicides, pesticide effects on the skin do not rank high on the list of hazard criteria. Hence, farmers are more concerned with avoiding pesticide inhalation or ingestion rather than direct skin exposure.

Herbicides are perceived less hazardous than insecticides and molluscicides. These chemicals, however, do not include category I rated active ingredients and are generally rated as less toxic than insecticides and molluscicides. In addition, herbicides are applied at the early stages of the crop cycle, so the farmer is spraying downward and does not have to pass through tall rice plants that he has just covered with pesticides; his exposure then to the chemicals is less.

Unsurprisingly, women have less knowledge of pesticides in general since they are not usually involved in spraying rice. However, 31 percent of the women bought the pesticides and 21 percent occasionally gave advice or made decisions related to pesticide application. There is no evidence that they are more concerned about pesticide hazards than the men.

**3.7. Farmer Precautions and Averting Behavior**

The most common precautions taken by the respondents are avoiding spraying in strong sun, wearing "protective clothes" such as long pants and long sleeved shirts, avoiding spraying against the wind, and washing afterwards. An extreme precautionary response was to get someone else to spray (Table 3.25). Farmers

Table 3.24. Reasons Given by Respondents from 162 Households for Choosing the Most Hazardous Pesticide, Nueva Ecija, 1991

| <i>Number of Respondents</i> | <i>Percent</i> | <i>Reason</i>                                                                                        |
|------------------------------|----------------|------------------------------------------------------------------------------------------------------|
| Insecticides:                |                |                                                                                                      |
| 65                           | 41.2           | Bad odor causes ill effects                                                                          |
| 31                           | 19.6           | Either they themselves or others had experienced bad effects while spraying                          |
| 20                           | 12.7           | Knew that the pesticide label, the color bands or skull and crossbones meant pesticide was hazardous |
| 17                           | 10.6           | Pesticide is dangerous (no further reason given)                                                     |
| 14                           | 8.8            | Pesticide harmed other animals so it must harm men as well                                           |
| 9                            | 5.7            | Pesticide affects the skin                                                                           |
| 1                            | 0.6            | Knew someone who had died from drinking it (intentionally)                                           |
| Herbicides:                  |                |                                                                                                      |
| 44                           | 27.8           | Bad odor causes ill effects                                                                          |
| 17                           | 10.8           | Affected the skin                                                                                    |
| 14                           | 8.9            | Pesticides have little effect                                                                        |
| 9                            | 5.7            | Knew from label on the bottle                                                                        |
| 8                            | 5.1            | Pesticide was dangerous (no further reason given)                                                    |
| 5                            | 3.2            | Herbicides were not dangerous to man because they only killed plants                                 |
| 2                            | 1.3            | Herbicides are hazardous to man because they kill plants                                             |
| Molluscicides:               |                |                                                                                                      |
| 62                           | 39.2           | Affected finger and toe nails                                                                        |
| 28                           | 17.7           | Bad odor caused ill effects                                                                          |
| 13                           | 8.8            | Pesticide harmed other animals so it must harm man as well                                           |
| 8                            | 5.1            | They themselves or others had experienced bad effects while spraying                                 |
| 8                            | 5.1            | Pesticide was dangerous (no further reason given)                                                    |
| 6                            | 3.8            | Knew from the label on the bottle                                                                    |
| 1                            | 0.6            | Pesticide had no effect                                                                              |

Table 3.25. The Most Common Methods of Avoiding Pesticide Contamination in the Field (Data from Field Surveys and Observation), Nueva Ecija 1991

| <i>Method</i>                                               | <i>Frequency of Respondents<br/>(percent)</i> |
|-------------------------------------------------------------|-----------------------------------------------|
| Avoids spraying when very hot (sprays as early as possible) | 72                                            |
| Wears a shirt or jacket with long sleeves                   | 71                                            |
| Avoids spraying against the wind                            | 66                                            |
| Avoids smoking while spraying                               | 61                                            |
| Wears long pants                                            | 52                                            |
| Wears a hat                                                 | 40                                            |
| Wears a cloth or mask over the nose and mouth               | 35                                            |
| Gets someone else to spray                                  | 20                                            |
| Eats or drinks something sweet before spraying              | 9                                             |
| Washes immediately afterwards (before taking a rest)        | 6                                             |

Note: None of the respondents wear gloves or boots while spraying pesticides on rice.

avoid spraying under the strong sun for fear of being poisoned or becoming ill, as many of them experienced.

### 3.7.1. *Use of Protective Clothing*

Thirty-five percent of the respondents wore some kind of mask, normally a T-shirt or handkerchief tied around their nose and mouth; wearing of boots or gloves is conspicuously absent (Table 3.25). Protective clothes worn by the farmers, however, are not really adequate to protect them.

Specialized clothing is not generally available, with the exception of some plastic aprons given by pesticide companies and, in the past, a few disposable masks. The clothes used by the spraymen, although giving some protection, will also absorb any pesticide spray and can cause secondary dermal exposure. In particular, cloth masks can gradually become impregnated with chemicals and cause more harm than good. For this reason, some spraymen avoid wearing masks or items like long trousers, which become soaked with pesticide-contaminated water. In these cases, absence of protective clothing cannot be taken as evidence that the spraymen take no precautions but, rather, that they believe that they do not give any benefit.

Almost all respondents bathe and change their clothes after spraying but not necessarily straight away. The majority take at least a short rest for about thirty minutes before washing. In fact, the rest itself is regarded as an averting behavior

against the ill effects of pesticides. Others wash hands and feet but do not change completely until they have finished all work for the day.

Results from observing spraymen in the field are consistent with answers given in the questionnaires. In addition, spraymen are very susceptible to accidental splashes of pesticides, especially while mixing. Mixing is usually done by pouring the concentrated chemical into the lid of the sprayer or pesticide bottle top and then into the sprayer. Since gloves are not worn, the concentrated chemical often splashes on to the hands.

The hazards of absorption of pesticides through the skin, especially the hands, appear to be underrated compared with precautions against inhalation and ingestion. No one mentioned protecting their hands or feet as a way of reducing risks from pesticides.

### 3.7.2. *Use of Gloves and Masks*

To assess attitudes to protective equipment, gloves, and dual cartridge respirators or "gas masks" were loaned to a randomly chosen subset of the sample. Gloves were chosen since they are one piece of equipment that give most protection, as the hands are particularly subject to pesticide exposure (Castañeda, Maramba, and Ordas, 1989). The masks, in turn, were recommended by pesticide applicators at International Rice Research Institute (IRRI) as the most important item of protective clothing. Black neoprene (chemical-resistant) gloves and the dual-cartridge respirators designed for agricultural sprays were loaned to the selected samples. The gloves are not available in the region, but the nearest equivalent is the unlined rubber laundry gloves. The closest equivalent mask available in the region are the light, dust masks, which cannot filter pesticide fumes.

The recipients of these equipment were shown how to use them; the items were then left with the recipients for the duration of the dry season. The items were later collected, and the recipients were asked what they thought of the equipment.

Despite most recipients saying that the items were useful, actual usage was fairly low. The gloves, for one, were too hot to wear. The masks were thought to be more useful than the gloves in providing protection but took the farmers some time to become accustomed to. Many of the recipients also found it difficult to breathe through the filters. This difficulty is increased by the hard, physical effort required to spray in the paddy fields. Actual usage of masks, however, was higher than the gloves. They were mostly used for spraying fruits and vegetables rather than the rice crop.

The use of gloves and masks illustrates the difficulties with protective equipment in the paddy environment. The equipment loaned was designed to be

Table 3.26. Logit Regression Results on Farmers' and Laborers' Willingness to Pay for the Gloves and Mask, Nueva Ecija 1991

|                  | Farmer                      |                              | Laborer                     |                             |
|------------------|-----------------------------|------------------------------|-----------------------------|-----------------------------|
|                  | Gloves                      | Mask                         | Gloves                      | Mask                        |
| Intercept        | -2.90<br>(5.70)             | 2.02<br>(6.10)               | -16.29<br>(6.70)            | -21.42<br>(7.50)            |
| Log of age       | -0.17<br>(1.00)             | -2.12 <sup>a</sup><br>(1.10) | 0.24<br>(1.20)              | -0.60<br>(1.20)             |
| Log of education | 1.29 <sup>b</sup><br>(0.60) | 1.10 <sup>a</sup><br>(0.70)  | 0.11<br>(0.60)              | -0.03<br>(0.70)             |
| Log of area      | 0.46<br>(0.40)              | 0.75 <sup>a</sup><br>(0.40)  | -0.55<br>(0.40)             | -0.28<br>(0.40)             |
| Log of income    | 0.04<br>(0.40)              | 0.27<br>(0.50)               | 1.50 <sup>c</sup><br>(0.60) | 2.38 <sup>c</sup><br>(0.80) |

Note: Figures in parentheses are standard errors of estimate.

a, b, c. Significant at the 1, 5, and 10 percent levels, respectively.

chemical resistant and for spraying agricultural chemicals. Despite this, farmers find them difficult to use. This raises the question of whether even good quality protective equipment is suitable under tropical conditions.

### 3.7.3. *Willingness to Purchase Personal Protective Equipment*

Logit analysis was used to determine the farmers' and laborers' willingness to purchase the two pieces of personal protective equipment: gloves and mask. The dependent variable is valued at one if the respondent is willing to pay for the equipment and valued at zero if he is not willing to pay for it. The willingness to purchase protective equipment is explained by age, education, farm area sprayed, and annual income. On the average, the farmer is forty-seven years old, an elementary school graduate, working on an average farm size of 1.70 ha (range: 0.20 to 7.5 ha), with an annual income of P 51,486. On the other hand, the laborer is younger at thirty-nine years old, also an elementary school graduate, working on a total farm size of 3.40 ha (range: 0.35 to 17.0 ha), with an annual income of P 23,310, about half of the farmer's income.

Table 3.26 shows the results of logit analysis. Age, farm size, and income did not affect the farmers' attitude in acquiring the gloves. Only education significantly affects the farmers' willingness to pay for the gloves. The more educated

the farmer, the more he is inclined to pay for the gloves. This coincides with the farmers' perception that dermal entry of pesticides is relatively unimportant.

Age, education, and farm size significantly affect farmers' willingness to pay for the mask in protecting themselves from pesticides' adverse effects. Thus, farmers are more willing to pay for the mask if they are young, more educated, and working on a larger area. For one, most younger farmers do the spraying by themselves in contrast to the older ones. Also, educated farmers are more likely to know the hazards of inhaling pesticides and likewise know that the larger the area, the more they are exposed to pesticide fumes. Income did not affect farmers' willingness to pay for either personal protective equipment.

For the laborers, income is the only significant attributing factor in their willingness to pay for the gloves and mask. That is, the higher the income, the more likely the laborer is to pay for gloves or mask.

### 3.8. Conclusions

Farmers are in no doubt that pesticides are hazardous, but their perceptions of relative hazard differ from the WHO ranking. Generally, category I and II chemicals are ranked higher than categories III and IV, with very little distinction between I and II. A strong odor is perceived as a main hazard indicator, and the emphasis is on avoiding inhalation or ingestion of the chemical. Insecticides and molluscicides are in general perceived as moderately hazardous while herbicides are slightly or less hazardous.

Although farmers and laborers are aware that pesticides are hazardous and the majority do take some action to protect themselves, workers in neither group protect themselves fully. In particular, there is a lack of awareness of the risks of absorption of pesticides through the skin. Despite most of the respondents saying that gloves and mask were useful, actual usage was fairly low. Actual usage of masks was higher than the gloves but mostly used for spraying fruits and vegetables rather than rice.

Age, education, and farm size significantly affect farmers' willingness to purchase protective equipment. This reaffirms the need for well-targeted training programs on the need for and safe use of pesticides.

### Notes

1. Sections 3.2 to 3.5 have been adapted from Chapter 4 of Rola and Pingali (1993).
2.  $LD_{50}$  = Lethal dose<sub>50</sub>. This is the amount of active ingredient of the compound required to kill 50 percent of the exposed population of organisms. The lower the  $LD_{50}$ , the more toxic the compound.
3. Fifty-five trained farmers had attended a two-day training at IRRI.

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# 4 MISUSE OF PESTICIDES AMONG RICE FARMERS IN LEYTE, PHILIPPINES

K.L. Heong, M.M. Escalada and A.A. Lazaro

## 4.1. Introduction

The market value of pesticides used in rice was estimated to be U.S. \$2.4 billion in 1988 (Woodburn, 1990). Japan was the largest consumer, accounting for 59 percent of the market, followed by South Korea (10 percent) and China (6 percent). The Philippine market was about U.S. \$48 million in 1988, with insecticides and herbicides accounting for 58 percent and 35 percent, respectively.

Large estimates of crop losses in tropical rice are often cited in the literature, and on average more seem to be lost to pests than was harvested (Teng, Torres, Nuque, and Calvero, 1990). Although these figures might only represent magnitudes of loss under abnormal and rare conditions, they nevertheless continue to be used by researchers and policymakers. Without corresponding information on the probabilities of occurrence and attainable yields, these figures are meaningless (Zadoks, 1992).

Farmers' pest management practices generally reflect their perceptions of pests (Tait and Napompeth, 1987; Mumford and Norton, 1984; Rola and Pingali, 1993). Most farmers believe that pests are major constraints to high yields (Litsinger, Price, and Herrera, 1980; Heong, 1984; Heong, Ho, and Jegatheesan, 1985; Rola and Pingali, 1993). They tend to spray pesticides to keep pests off

their rice crops rather than to prevent yield loss. Such attitudes would lead to pesticide misuse.

In this paper, we analyzed the types of chemicals farmers used in Leyte during the wet season, the pest targets, and the timing of sprays, to assess misuse. Approaches to improve current practices are discussed.

## **4.2. Methods**

Leyte is an island located in the Eastern Visayas region of the Philippines. It has a total land area of 6,270 square kilometers with a population of about 1.5 million. Agriculture is a major economic activity with coconut, rice, sugar, and corn as principal crops. Of the 98,000 hectares cultivated to rice, about 72 percent is irrigated, 23 percent rainfed, and the remaining 5 percent upland rice.

Data on farmers' pesticide use were obtained using structured personal interviews. The survey questionnaire was translated into Cebuano and Waray, the two local languages spoken in Leyte. It was pretested on twenty-five farmers, and the questionnaires were modified. The modified questionnaire was then further tested on another ten farmers before the final version was prepared. The survey was conducted with the assistance of three students of Development Communication trained in basic survey techniques. All the interviews were conducted in May 1991. In addition, personal interviews with farmers were conducted by the authors, in which answers were further examined.

Three hundred farmers from eight municipalities in Leyte were selected for the interviews. From a list of rice growing villages in the municipalities, thirty villages were randomly selected, and from each village, ten farmers were randomly chosen. To ensure accuracy in the pesticides used, farmers were requested to show the interviewers used bottles of the pesticides.

The questionnaire data were coded and entered into a spreadsheet program using a microcomputer. After validation, the data file was uploaded to the mainframe IBM 4361 at the International Rice Research Institute. Frequency tables were generated using the FREQ procedure available in Statistical Analysis Systems (SAS, 1985).

## **4.3. Results**

About 88 percent of the farmers interviewed sprayed at least once during the season. Almost half (45 percent) of the farmers sprayed two or three times a season, and another third (33 percent) sprayed more than three times. About 12 percent did not use any pesticides, while 10 percent used once. Most (78 percent)

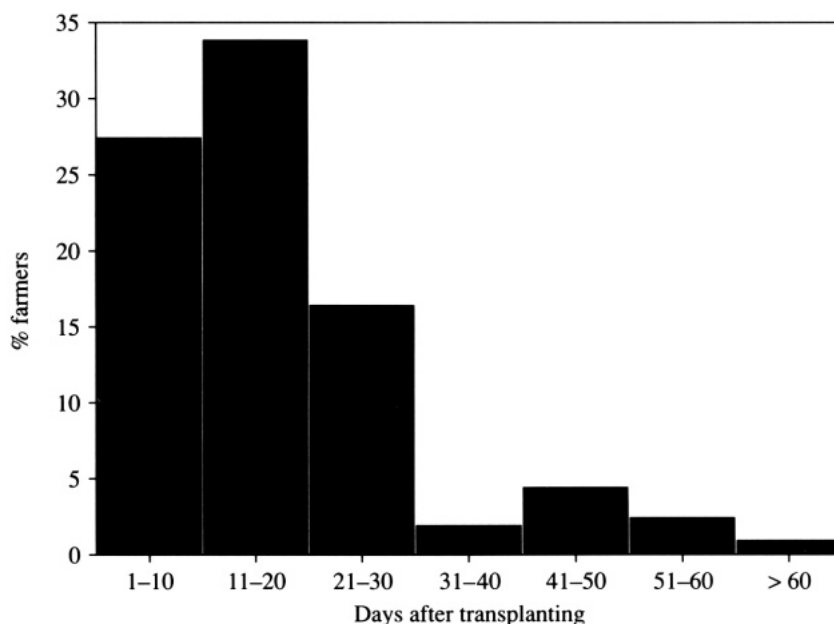


Figure 4.1. Distribution of Rice Farmers' First Pesticide Sprays in Leyte, Philippines

of the farmers applied their first pesticide sprays in the first thirty days after transplanting (DAT) (Figure 4.1).

The 300 farmers interviewed applied a total of 841 sprays. The average sprays per farmer was 2.8. Table 4.1 shows the variety of pesticides used in the different crop stages. At seedling and tillering stages, endosulfan was most commonly used, followed by monocrotophos. At booting, flowering and milky stages, methyl parathion was most common followed by cypermethrin.

Most of the pesticides (92 percent) used were insecticides. Only 4.1 percent and 3.9 percent of the applications were fungicides and herbicides, respectively. Of the insecticides, five chemicals constituted 84 percent of the total sprays. These were endosulfan (21 percent), methyl parathion (21 percent), cypermethrin (17 percent), monocrotophos (13 percent), and chlorpyrifos (11 percent). Using hazard classifications of the World Health Organization (WHO), 17 percent of the chemicals used by the farmers were in category Ia (extremely hazardous), 20 percent in category Ib (highly hazardous), and 59 percent in category II (moderately hazardous).

The intended target pests of the pesticide sprays by the farmers are shown in



Table 4.2. For rice bugs, farmers used methyl parathion (27 percent), cypermethrin (19 percent), and endosulfan (15 percent), while for snail control, endosulfan was most common (67 percent) and some (29 percent) used a fungicide, fentin chloride. To control leaffolders and other lepidopterous larvae, farmers mainly used methyl parathion (15 percent), monocrotophos (17 percent), endosulfan (19 percent), and cypermethrin (15 percent). Farmers did not consider leaf and planthoppers to be important, but about 6 percent of the sprays were targeted at them. The main chemicals used were chlorpyrifos, methyl parathion, cypermethrin, and monocrotophos, which accounted for 73 percent of all the sprays used for these pests. Only a few (6 percent) used carbamates. About 10 percent of the farmers reported spraying against ladybird beetles, and these accounted for 4 percent of sprays used. The main insecticides used were methyl parathion, endosulfan, cypermethrin, and monocrotophos.

Table 4.3 shows the proportion of sprays used against the main pests at different crop stages. A large proportion of the spraying for snail control was carried out in the nursery (73 percent) and at early tillering (20 percent). For rice bugs, most of the sprays were carried out at the booting (35 percent) and flowering (24 percent) stages, while only a third were used in the milky (17 percent) and soft dough (17 percent) stages. Most of the sprays for leaffolder control were carried out in the early tillering (36 percent), late tillering (31 percent), and booting (21 percent) stages, while some (10 percent) were used in the nursery. Similarly, the control of other lepidopterous larvae were also done during the early tillering (34 percent), late tillering (27 percent), booting (15 percent), and nursery (17 percent) stages. For stemborer control, most sprays were carried out in the early tillering (23 percent), late tillering (44 percent), and booting (21 percent) stages.

#### 4.4. Discussion

Misuse is defined as the “improper or incorrect use” (*New Lexicon Webster’s Dictionary*, 1991). Thus, when a pesticide is used for the wrong target pest or at the wrong time or both, it can be considered to be misused. However, farmers tend to use pesticides as killing agents, which is perhaps the main reason farmers use methyl parathion, endosulfan, monocrotophos, cypermethrin, and fentin chloride. These chemicals are extremely toxic not only to pests but to humans as well. Methyl parathion, for instance, has a mammalian toxicity of less than 15 mg/kg and is classified by WHO as extremely hazardous. About 60 percent of this insecticide had been used for rice bug control. Rice bugs (*Leptocoris* spp.) commonly colonize ricefields in the tillering and ripening stages, but they are pests only during the milky stage, which lasts seven to ten days. However,

Table 4.2. Pest Targets of Pesticides Used by Rice Farmers in Leyte, Philippines

| Pesticides           | Percentage of Sprays of Each Pesticide Used for Each Pest |                 |             |        |             |              |            |       |      |        |                          |                          |
|----------------------|-----------------------------------------------------------|-----------------|-------------|--------|-------------|--------------|------------|-------|------|--------|--------------------------|--------------------------|
|                      | Golden                                                    |                 |             | Rice   |             |              | Cut        |       |      | Whorl  |                          |                          |
|                      | Rice Bug                                                  | Ladybird Beetle | Apple Snail | Tungro | Leaf Folder | Mole Cricket | Stem Borer | Blast | Worm | Maggot | Lepidopterous LeafFeeder | Green Brown Plant Hopper |
| <b>Insecticides:</b> |                                                           |                 |             |        |             |              |            |       |      |        |                          |                          |
| Organochlorines:     |                                                           |                 |             |        |             |              |            |       |      |        |                          |                          |
| Endrin               | 0.3%                                                      | 0.0%            | 0.0%        | 0.0%   | 0.9%        | 0.0%         | 0.0%       | 0.0%  | 0.0% | 0.0%   | 0.0%                     | 0.0%                     |
| Endosulfan           | 15.2                                                      | 16.7            | 66.7        | 41.7   | 7.3         | 0.0          | 16.3       | 33.3  | 50.0 | 0.0    | 30.0                     | 8.6 7.1                  |
| Organophosphates:    |                                                           |                 |             |        |             |              |            |       |      |        |                          |                          |
| Chlorpyrifos         | 9.0                                                       | 2.8             | 0.0         | 16.7   | 12.7        | 0.0          | 10.5       | 0.0   | 0.0  | 66.7   | 10.7                     | 20.0 28.6                |
| Methyl parathion     | 26.5                                                      | 36.1            | 0.0         | 8.3    | 16.4        | 100.0        | 16.3       | 0.0   | 0.0  | 0.0    | 13.3                     | 17.1 21.4                |
| Monocrotophos        | 8.2                                                       | 16.7            | 0.0         | 8.3    | 12.7        | 0.0          | 17.4       | 11.1  | 50.0 | 0.0    | 20.8                     | 28.6 0.0                 |
| Azinphos-ethyl       | 1.4                                                       | 0.0             | 0.0         | 0.0    | 3.6         | 0.0          | 4.7        | 0.0   | 0.0  | 0.0    | 0.0                      | 2.9 0.0                  |
| Cyhalothrin          | 2.5                                                       | 0.0             | 0.0         | 0.0    | 2.7         | 0.0          | 0.0        | 0.0   | 0.0  | 0.0    | 1.7                      | 0.0 0.0                  |
| Malathion            | 0.6                                                       | 0.0             | 0.0         | 0.0    | 0.9         | 0.0          | 3.5        | 0.0   | 0.0  | 0.0    | 0.8                      | 0.0 0.0                  |
| Triazophos           | 0.3                                                       | 0.0             | 0.0         | 0.0    | 0.9         | 0.0          | 1.2        | 0.0   | 0.0  | 0.0    | 0.0                      | 0.0 0.0                  |
| Methamidophos        | 0.0                                                       | 0.0             | 0.0         | 0.0    | 4.5         | 0.0          | 0.0        | 0.0   | 0.0  | 0.0    | 0.0                      | 0.0 0.0                  |
| Carbamates:          |                                                           |                 |             |        |             |              |            |       |      |        |                          |                          |
| MIPC                 | 2.5                                                       | 0.0             | 0.0         | 8.3    | 2.7         | 0.0          | 2.3        | 0.0   | 0.0  | 0.0    | 1.7                      | 2.9 14.3                 |
| BPMC                 | 0.6                                                       | 0.0             | 0.0         | 0.0    | 3.6         | 0.0          | 0.0        | 0.0   | 0.0  | 0.0    | 0.0                      | 2.9 0.0                  |
| Carbosulfan          | 0.0                                                       | 0.0             | 0.0         | 0.0    | 0.0         | 0.0          | 0.0        | 0.0   | 0.0  | 0.0    | 0.8                      | 0.0 0.0                  |
| Pyrethroids:         |                                                           |                 |             |        |             |              |            |       |      |        |                          |                          |
| Cypermethrin         | 19.2                                                      | 16.7            | 0.0         | 0.0    | 17.3        | 0.0          | 17.4       | 33.3  | 0.0  | 0.0    | 12.5                     | 8.6 21.4                 |

[illegible]





only 34 percent of the sprays were applied in the milky or soft dough stages. Rice bugs are highly mobile and tend to move between fields (Rothschild, 1970). Thus, spraying for rice bugs at the nursery, tillering, and flowering stages has no impact on crop protection.

Similarly, using insecticides to control leaf-feeding insects at the early crop stages generally do not increase yields. The most common species that infest the rice crop at these stages is the rice leaffolder, *Cnaphalocrocis medinalis*. Crops with as much as 67 percent damaged leaves did not suffer any loss (Miyashita, 1985). Although the economic threshold was estimated to be 1.5 larvae per hill by Bautista, Heinrich, and Rejesus (1984), it was grossly overestimated by at least four times (Heong, 1990) and should be adjusted to five to six larvae (Heong, 1993). Such densities are extremely rare. In the Philippines, the average density observed is less than one larva per hill (Guo, 1990). Ladybirds, *Micraspis* sp., are common predators and pollen feeders in ricefields, but farmers mistake them for pests and spray against them. Generally, the hoppers *Nilaparvata lugens* and *Nephotettix virescens* are found in ricefields at low densities in the early crop stages (Heong, Aquino, and Barrion, 1991) and do not cause any crop loss. However, farmers spray to get rid of them. The golden apple snail, is a relatively new pest problem in the Philippines (Adalla and Rejesus, 1988). There was no molluscicide suitable for ricefields available in the Philippines, and most farmers used chemicals that would kill snails, like organotin fungicides, fentin chloride, and fentin acetate. Another commonly used chemical was endosulfan, an insecticide with adverse effects on aquatic fauna. These were clearly misuses of pesticides.

Of the 841 sprays, only 190 or 23 percent may be considered to be applied at the appropriate time for the intended targets. Out of this, only 160 or 19 percent have used a chemical that can affect the intended pests and in some way prevented yield loss. Thus more than 80 percent of the sprays applied by farmers in Leyte during the 1991 wet season can be considered to be misuse of pesticides.

In the early crop stages, the rice ecosystem is usually inhabited by species that are herbivores, predators, and detritivores (Heong, Aquino, and Barrion, 1991). Among the herbivores, plant and leaf hoppers are usually predominant, but they do little damage to the crop. The most visible injuries in the crop are often due to a few lepidopterous species. Thus, during these early crop stages, insecticide sprays were unnecessary. Yet 78 percent of the farmers applied their first sprays in the first thirty DAT. Insecticide inputs at these early crop stages are not only wasteful but can be damaging to the predator-prey balance that may lead to secondary pest outbreaks, like the brown planthopper (Heinrichs and Mochida, 1984; Heong, 1991).

Highly visible and colorful species, such as the rice bug, golden apple snail, ladybird, and lepidopterous larva, are often perceived to be damaging and farmers

tend to overreact toward them (Bentley, 1989; Bentley and Andrews, 1991; Escalada and Heong, 1993). These species were the targets of 80 percent of the sprays in Leyte. It thus seems that indigenous attitudes, such as a belief that insects, particularly worms (or ulod) and snails are harmful, tend to make farmers become victims of pesticide abuse (Bentley, 1989).

As pesticide misuse is high, programs that focus on eliminating misuse may be beneficial to farmers. Misuse may be due to widespread gaps in farmers' perceptions of rational pest management (Escalada and Heong, 1993). To bridge these gaps and improve farmers' pest management practices, several communication approaches have been employed. They generally utilize either mass media or interpersonal channels or a combination. The choice of which communication approach to employ will depend on project objectives and resources. Among the extension and communication approaches used in rice pest management, strategic extension campaigns (Escalada and Kenmore, 1988), radio-based campaigns (Pfuhl, 1988), farmer field schools (Kenmore, 1991), and farmer participatory research (Escalada and Heong, 1993) stand out in bringing about changes in farmer practices. While extension and radio-based campaigns have greater reach, farmer participation methods, like the farmer field schools and farmer participatory research, may have more impact through experiential learning. Because of their experiential character, learning from participatory approaches that eventually impact on changes in practices may tend to be more sustainable. As pointed out by Minnick (1989), individuals generally retain 70 percent of the information taught if they learn it by seeing and doing.

Several human and social factors influences farmers' deeply entrenched perceptions of pests and pesticide use. These include the association of pesticides with medicine, risk aversion, media messages, and pesticide promotion campaigns (Escalada and Heong, 1993). To initiate changes in pest management decision making would require learning of basic concepts and applying them. Farmer participatory approaches, like the farmer field schools and farmer participatory research, would have greater impact in changing attitudes and practices.

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# 5 BEHAVIOR OF PESTICIDES IN RICE-BASED AGROECOSYSTEMS: A REVIEW

P.A. Roger and S.I. Bhuiyan

## 5.1. Introduction

Emphasis on agricultural production using modern techniques has focused attention on the problem of yield losses due to pests and the need for adequate protection of the crop. Pesticide application is currently the most widely practiced method of pest control in rice and rice-based cropping systems. Because of their toxic nature there is a general concern with the potential hazards of pesticides to humans and the environment.

The fate of pesticides applied in agricultural ecosystems is governed by the transfer and degradation processes and their interactions. Transfer is a physical process in which the pesticide molecules remain intact; it includes sorption-desorption, runoff, percolation, volatilization and absorption by crop plants or animals. Degradation is a chemical process in which pesticide molecules are split; it includes photodecomposition, microbiological decomposition, chemical decomposition, and plant detoxication. Transfer and degradation determine pesticide persistence or retention, its efficacy for pest control, as well as its potential for contamination of the soil and water resources.

Growing evidence indicates that pesticides are present in food grown on the land in surface and subsurface bodies of water and in the atmosphere. Research



has established the toxic effects of some pesticides on fish and other aquatic animals, on birds and other wildlife, and on human health. There is therefore a growing interest in understanding the processes relevant to the transport, transformation, and retention behaviors of pesticides used in agricultural production systems.

This paper reviews the information on the fate of pesticides in rice-based agroecosystems with emphasis on wetland soils.

Early studies of the fate of pesticides in soils have dealt mostly with upland soils. The bibliographic review on microbial transformation and decomposition of pesticides by Hill (1978) includes 334 references, among which only six refer to flooded soils. Similarly, the review of microbial degradation of insecticides by Matsumura and Benezet (1978) lists 133 references but only ten on submerged soils.

During the 1970s, interest in pesticide fate in wetland rice soils developed, especially with the studies conducted by Sethunathan and his coworkers, who authored between 1969 and 1984 more than fifty papers on this topic. Work on microbial degradation of insecticides in flooded rice soils was reviewed by Sethunathan (1973a) and Sethunathan and Siddaramappa (1978). About 100 pesticide studies dealing with ricefields, rice soils, or organisms isolated from ricefields were published during the 1970s. The number falls to about fifty in the 1980s. Since 1990 very few pesticide studies have dealt with ricefields.

## **5.2. Pesticide Use in Wetland Rice Fields**

### **5.2.1. *Pesticide Categories***

In most rice-growing countries, insecticides are the dominant class of pesticides used (Van der Valk and Koeman, 1988). In the Philippines, for example, 55 to 60 percent of the pesticides used before 1980 were insecticides, 20 to 25 percent fungicides, and 5 to 16 percent herbicides. However, herbicide use is increasing rapidly due to the escalating costs of labor in many areas (Moody, 1990). Molluscicides have recently been introduced in some rice-growing regions in Asia where golden snails (*Pomacea canaliculata*) have become a threat to rice seedlings.

### **5.2.2. *Quantities of Pesticide Applied***

In recent years, pesticide use has increased more rapidly in developing countries than in the developed countries. This trend toward pesticide usage is a cause for concern (Moody, 1990).

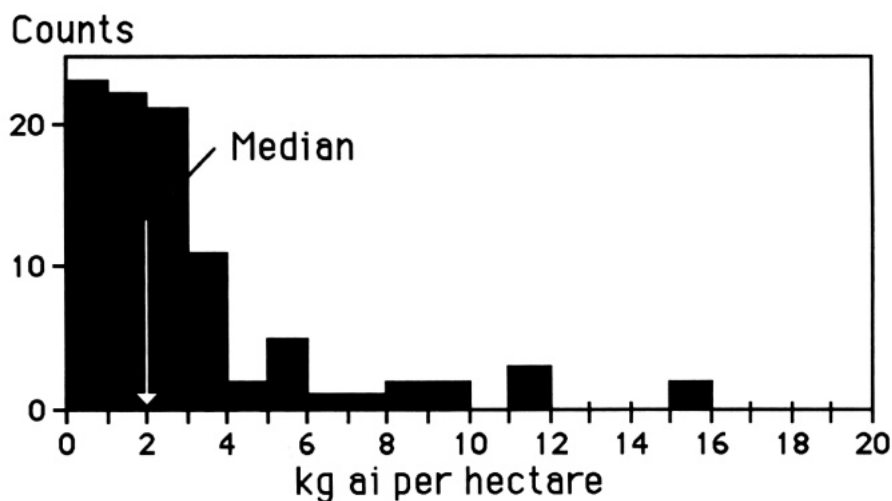


Figure 5.1. Histogram of the Average Recommended Doses of Ninety-Four Pesticides Tested for Their Microbiological Effects in Ricefields

**5.2.2.1. Recommended Application Rates.** Recommended level for field application (RFLA) of traditional pesticides range from a few hundred grams to a few kilograms (kg) active ingredient per hectare (ai/ha), with a median of about 2 kg (Figure 5.1). The median is higher for herbicides (2.5 kg ai/ha) than for fungicides (1.7 kg ai/ha) and insecticides (1.1 kg ai/ha) (Roger, 1990).

When interpreting the results of experiments on pesticide, it is important to appreciate that application rates do not necessarily equate with exposure concentration. The upper limit of the range of pesticide concentrations that can be expected in farmer fields after application can be calculated by assuming that pesticide is applied on a nonflooded soil and remains in its first two centimeters. In this case, 1 kg ai/ha corresponds to 10 parts per million (ppm) on dry soil basis (bulk density 0.5). A lower limit can be calculated by assuming an even distribution in 10 centimeters (cm) of water and 10 cm of puddled soil of a water-soluble pesticide. In this case, 1 kg ai/ha corresponds to 0.4 ppm. Field concentrations are probably closer to the lower level.

**5.2.2.2. Farmers' Behavior.** In irrigated rice farming using high-yielding varieties, chemical pesticide use is a common practice. However, rice farmers in developing countries frequently ignore recommended pesticide application regimes. Both excessive and reduced application have been reported.

Application can be excessive in term of quantity used per application, when

fanners apply more than the recommended dose, or in terms of unnecessary applications, especially when farmers use chemical pesticides in prophylactic applications expecting to prevent pest infestation or to keep the pest population low.

A survey conducted in 1989 by International Rice Research Institute (IRRI) in thirty-two farms of the Laguna area in the Philippines indicated a wide range of pesticide use in terms of formulation (twenty-one) and quantity. The total quantity of pesticide used during a cropping season in a field ranged from 0.5 to 2.5 kg ai/ha. Most values were between 1 and 2 kg ai/ha. The quantities of individual pesticides used per cropping season averaged 0.3 kg ai/ha and did not exceed 1 kg ai/ha. The values were often below the recommended dose (Roger et al., 1990).

### **5.3. Methods of Studying Pesticide Behavior in Rice Production System**

Many experiments studying the fate of pesticide in ricefield soils are small-scale laboratory experiments in test tubes or beakers. Microcosms and models have also been used. Field experiments are less numerous.

#### **5.3.1. *Small-Scale Experiments***

Most studies of pesticide degradation in soil were performed as laboratory experiments with a few grams of soil. Under such conditions pesticide degradation might be underestimated because of

- The absence of the rhizospheric effect, which may enhance pesticide degradation;
- The absence of rice plants and wind, which may increase pesticide loss by volatilization;
- The absence of variations of environmental conditions (temperature, redox, light, wind, etc.); and
- The high pesticide concentrations sometimes used in such experiments, which may overestimate pesticide persistence because high concentrations slow down pesticide degradation as shown with trifluralin (Parr and Smith, 1973) or molinate (Deuel, Turner, Brown, and Price, 1978).

#### **5.3.2. *Microcosms and Scale Models***

Several authors have tried to develop small-scale models (microcosms) of rice-fields or aquatic ecosystems to study the fate of pesticides. Such models offers an interesting alternative to field studies, which are often more expensive and difficult to control. Chen, Err-Lieh, and Chen (1982) used a microcosm including

rice plants and ten organisms (grasshopper, brown planthopper, mosquito larva, wolf spider, water flea, dragonfly naiad, giant duckweed, mosquito fish, algae, and snails) to study the fate of  $^{14}\text{C}$  labeled thiobencarb. However utilization of sand instead of soil in the model ecosystem might have biased the results. Tomizawa (1980) and Tomizawa and Kazano (1979) used a similar approach to study the persistence and bioaccumulation of several rice pesticides in the environment. Tejada and Magallona (1986) used a model ecosystem to study bioaccumulation of carbofuran in fish grown in a rice-fish system. Microcosms were also designed by Au (1980), Isensee, Kaufman, and Jones (1982), Lichtenstein, Liang, and Koeppel (1983), Seiber, McChesney, Sanders, and Woodrow (1986), Higashi and Crosby (1987) and Mostafa, El-Arab, and Zayed (1987) to study or predict the dissipation of various pesticides applied to flooded ricefields. Major characteristics of ricefield microcosm studies are summarized in Higashi (1987).

Microcosm studies may lead to erroneous conclusions if environmental conditions are not properly reproduced. Comparing molinate dissipation under field and microcosm conditions mimicking day-night light and temperature cycles, Higashi (1987) found only 15 percent difference in the estimations from both methods, which was acceptable. But in comparing bentazon dissipation under both diurnal cycle and constant light conditions in a microcosm, he found that the results gave opposite conclusions—namely that it does and does not accumulate. He established that the field-mimicking microcosm experiment (diurnal light cycle) was closer to field observations.

### 5.3.3. *Field Trials*

Few field trials have been used for monitoring the persistence of pesticides. When several samples were collected in the same field, a high variability of the concentrations was observed; for example, determinations of propanil in four soil samples from the same field forty days after application ranged from less 0.01 ppm to 0.2 ppm (Kearney, Smith, Plimmer and Guardia, 1970). This high variability results, at least partly, from the importance of microbial activities in the degradation of pesticides and the aggregative distribution of microorganisms in the soil. Therefore, sampling strategies adapted to microbiological studies *in situ* (Roger, Jimenez, and Santiago-Ardales, 1991) must be used in pesticide persistence studies.

### 5.3.4. *Simulation Models*

Pesticide behavior in the ecosystem is very complex and determined by many variables and their interactions. Although the basic processes involved in their fate after application are established, it is difficult as well as expensive to adequately characterize them experimentally, taking account of the interactions,

over the range of physical conditions that are of interest. Therefore, the mathematical modeling technique using microcomputers has proved to be an attractive alternative for predicting various aspects of pesticide behavior. However, successful simulation modeling requires accurate mathematical formulation of the various component behaviors of applied pesticide and construction of the relational model that would adequately represent the processes governing pesticide behaviors. Much more research has to be done to achieve the progress needed in this area in order to allow development of comprehensive pesticide behavior models for practical use.

In recent years several simulation models have been developed to determine the fate of pesticide, ranging from pesticide spray behavior to pesticide retention in soil profile, leaching to groundwater, or degradation in freshwater bodies. These models are by no means simple to apply in all cases or universally applicable. Furthermore, the few well-tested models that are available were developed for important field crop systems of the temperate climate. Examples are the Bragg spray model (Bragg, 1981) for spray drift in pesticides applied by aircraft, the PRZM model (Carsel et al., 1984) to simulate vertical pesticide movement in the root zone or the unsaturated soil above water table, and the CREAMS model (Knisel, 1980) designed to determine runoff pesticide load from agricultural production systems. Since the ricefield ecosystem in wetland culture is quite unique, the applicability of the models to rice ecosystem is therefore often limited. However, with appropriate modifications some of the models could be adapted to the local ricefield conditions. A practical limitation of adapting and readily using most simulation models for ricefield ecosystems in Asia is the lack of data that are needed for parameter calibration.

Very few studies have been conducted on developing models to establish pesticide behavior in ricefields. Seiber, McChesney, Sanders and Woodrow (1986) calculated volatilization rates of MCPA, thiobencarb, and molinate from water using a computer model (EXAMS) and measured them in a laboratory chamber and in flooded ricefields. A fair to good correlation was obtained between EXAMS-calculated and chamber-measured rates for all three herbicides. Field-measured values correlated well with chamber measured rates for thiobencarb and molinate. For MCPA, field-measured values were much higher than expected for volatilization from water alone. In this case, the presence of plant and other surface residues in the field made the major contribution to measured volatilization.

#### **5.4. Decomposition of Pesticides in Wetland Soils**

As in any cultivated soil, the metabolism and effects of pesticides in ricefields depend on soil properties, climatic factors, the method of pesticide application,

and synergistic-antagonistic effects among pesticides and between pesticides and fertilizers. However, pesticide behavior in ricefields presents characteristics specific to wetland conditions. In particular, their degradation in tropical ricefields is favored by (1) temperatures and pH, which usually stabilizes in a range (6.7 to 7.2) favoring microbial activity (Ponnampereuma, 1972), and (2) reducing conditions caused by submersion and further accelerated by organic matter incorporation. This results in rapid detoxication of certain pesticides known to persist in aerobic environment (Sethunathan and Siddaramappa, 1978).

#### 5.4.1. *Mechanisms and Chemical Pathways of Pesticide Decomposition*

**5.4.1.1. Microbiological Decomposition.** A usually much faster degradation of pesticides in nonsterile than in sterilized (autoclaved) soils demonstrates the importance of their microbial degradation (Figure 5.2). Microbial involvement in pesticide degradation is also indirectly established by (1) an initial lag in degradation followed by a faster loss attributed to microorganisms adaptation, (2) an initial lag becoming shorter with repeated application of the same pesticide, due to the enrichment of the microflora in pesticide-degrading microorganisms, (3) inhibition of pesticide degradation after addition of antibiotics or bacteriostatics to soil-water cultures, and (4) increased decomposition after soil inoculation with enrichment cultures. Direct demonstration is done by the isolation of microorganisms that are able to degrade pesticides in pure culture (Adhya, Sudhakar-Barik, and Sethunathan, 1981b, 1981c; Rajagopal, Brahmaprakash, and Sethunathan, 1984).

Pesticide-decomposing microorganisms isolated from ricefield soils belong to the genera *Arthrobacter*, *Bacillus*, *Clostridium*, *Flavobacterium*, *Micrococcus*, *Mycobacterium*, *Pseudomonas*, and *Streptomyces* (Table 5.1). Microorganisms can degrade pesticides using them as sole carbon source, through cometabolism, or by synergy. For example, Sethunathan (1972) reported one species (*Flavobacterium* sp.) that used diazinon as sole carbon source, five species degrading it by cometabolism (*Arthrobacter* sp., *Corynebacterium* sp., *Pseudomonas melophthora*, *Streptomyces* sp. and *Trichoderma viride*), and two species acting in synergy (*Arthrobacter* sp. + *Streptomyces* sp.).

The relative importance of microbial degradation varies considerably between soils and pesticides. The half-life of gamma BHC was about forty-five days in a nonsterilized soil and about eighty days in the same soil that had been sterilized (Raghu and MacRae, 1966). Trifluralin was almost not decomposed after twenty days in a sterilized soil while it had almost completely disappeared in the same unsterilized soil enriched with alfalfa meal (Parr and Smith, 1973).

In upland conditions, bacteria and fungi are considered to be mainly responsible

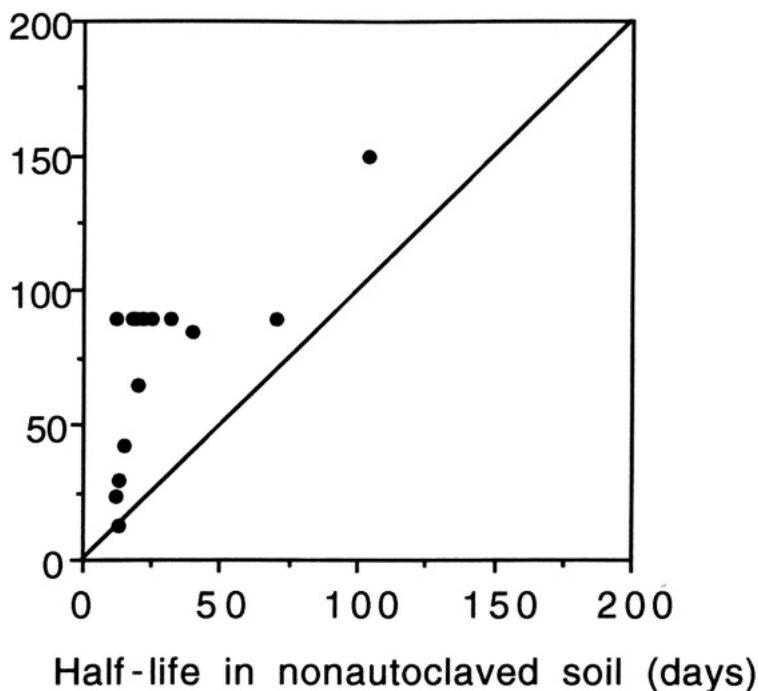


Figure 5.2. Stability of Thirteen Pesticides in Autoclaved and Nonautoclaved Soils

Source: Drawn from data by Agnihotri (1978); Funayama, Uchida, Kanno, and Tsuchiya (1986); Gowda and Sethunathan (1976); MacRae, Raghu, and Castro (1967); Nakamura, Ishikawa, and Kuwatsuka (1977); Raghu and MacRae (1966); Sethunathan and MacRae (1969); Siddaramappa, Tirol, and Watanabe (1979).

for pesticide transformations in soils. In wetland soils, fungi are involved (Rao and Sethunathan, 1974) but are probably less important, whereas microalgae might have a significant role. Sato and Kubo (1964) found that parathion was degraded within a few days in ricefields and that the presence of algae greatly accelerated the degradation rate.

Experiments in flasks have shown that the toxic effect of BHC, HCH, and carbofuran on axenic cultures of BGA was reduced by repeated inoculation and removal of the algae (Das and Singh, 1977; Kar and Singh, 1979). The mechanism of toxicity reduction was not elucidated; it could have been pesticide degradation by the alga, accumulation and removal with harvested algae, or spontaneous degradation of the pesticide.

Table 5.1. Pesticide Degrading Microorganisms Isolated from Ricefields

| <i>Pesticide</i>     | <i>Microorganism</i>          | <i>Reference</i>                                     |
|----------------------|-------------------------------|------------------------------------------------------|
| Benzene hexachloride | <i>Clostridium</i> sp.        | – Sethunathan, Bautista, and Yoshida, 1969           |
| Carbaryl             | <i>Pseudomonas cepacia</i>    | – Venkateswarlu, Chendrayan, and Sethunathan, 1980   |
| Carbofuran           | <i>Arthrobacter</i> sp.       | – Rajagopal, Rao, Nagendrapa, and Sethunathan, 1984  |
| Carbofuran           | <i>Bacillus</i> sp.           | – Rajagopal, Rao, Nagendrapa, and Sethunathan, 1984  |
| Carbofuran           | <i>Micrococcus</i> sp.        | – Rajagopal, Brahmaprakash, and Sethunathan, 1984    |
| Diazinon             | <i>Arthrobacter</i> sp.       | – Sethunathan and Pathak, 1971                       |
| Diazinon             | <i>Arthrobacter</i> sp.       | – Sethunathan, Adhya and Raghu, 1982                 |
| Diazinon             | <i>Flavobacterium</i>         | – Yoshida, 1975                                      |
| Diazinon             | <i>Flavobacterium</i> sp.     | – Sethunathan, 1972                                  |
| Diazinon             | <i>Streptomyces</i> sp.       | – Sethunathan and MacRae, 1969                       |
| Gamma BHC            | <i>Clostridium rectum</i>     | – Ohisa and Yamaguchi, 1978b                         |
| Gamma BHC            | <i>Clostridium</i> sp.        | – Sethunathan and Yoshida, 1973b                     |
| HCH                  | <i>Clostridium sphenoides</i> | – Heritage and MacRae, 1979                          |
| Heptachlor           | <i>Clostridium</i> sp.        | – Sethunathan and Yoshida, 1973b                     |
| Lindane              | <i>Clostridium</i> sp.        | – MacRae, Raghu, and Bautista, 1969                  |
| Metoxychlor          | <i>Clostridium</i> sp.        | – Sethunathan and Yoshida, 1973b                     |
| Parathion            | <i>Bacillus</i> sp.           | – Siddaramappa, Rajaram and Sethunathan, 1973        |
| Parathion            | <i>Bacillus</i> sp.           | – Sudhakar-Barik, Siddaramappa and Sethunathan, 1976 |
| Parathion            | <i>Flavobacterium</i> sp.     | – Sethunathan and Yoshida, 1973a                     |
| Parathion            | <i>Pseudomonas</i> sp.        | – Siddaramappa, Rajaram and Sethunathan, 1973        |
| Parathion            | <i>Pseudomonas</i> sp.        | – Sudhakar-Barik, Siddaramappa and Sethunathan, 1976 |
| Pentachlorophenol    | <i>Mycobacterium</i> sp.      | – Suzuki, 1983a, 1983b                               |
| Pentachlorophenol    | <i>Pseudomonas</i> sp.        | – Watanabe, 1973b                                    |
| Pentachlorophenol    | <i>Pseudomonas</i> sp.        | – Suzuki, 1983a, 1983b                               |

Rhizospheric bacteria may play a significant role in pesticide degradation. In an unplanted flooded soil, less than 5.5 percent of the  $^{14}\text{C}$  of labeled parathion was evolved as  $^{14}\text{CO}_2$  in two weeks whereas 22.5 percent was evolved in planted soil (Rajasekhar and Sethunathan, 1983a). However, a rhizosphere effect on pesticide decomposition is not due to microbiological activity only. Mineralization of parathion in the rhizosphere of rice was more pronounced at the seedling stage than at the maximum tillering and panicle initiation stages; the degree of rhizosphere effect depended on the rice variety and was related to the root oxydase activity in rice but not necessarily to the biomass of the plant (Rajasekhar and Sethunathan, 1983b).



**5.4.1.2. Nonbiological Decomposition.** Pesticide degradation observed in the absence of biological activity indicates that physical and chemical processes are also involved. Rao and Sethunathan (1979) highlighted the importance of chemical transformations catalyzed by redox reactions such as the iron redox system.

Photodecomposition at soil and water surfaces is also important, particularly when exposed to direct sunlight. Under laboratory conditions, butachlor exhibited 95 percent decomposition after twenty-four hours of exposure to light. *In situ*, marked differences in half-life, which varied from five days to 0.8 day, were attributed to changes in climatic conditions, temperature and light intensity (Chen, 1980).

The relative importance of nonbiological degradation varies with pesticides and environmental conditions. For various insecticides, it ranged from 30 to 90 percent of the degradation in soil in the presence of microflora (Agnihotri, 1978). Degradation of carbofuran in water was mainly by nonbiological processes and was related to the initial pH; but in soil, it was associated with microbial activities (Siddaramappa and Seiber, 1979).

Beside microbiological and chemical degradation-transformation, pesticides can disappear from the ricefield through volatilization (see Section 5.5.2) and plant detoxication. The structure of many organic pesticides are altered by resistant plants; even susceptible plants may metabolize small amounts of pesticides.

Several pathways of degradation-dissipation can affect a single pesticide. Their relative importance varies, depending on environmental conditions. For example, trifluralin is decomposed both by physicochemical and microbiological processes. Degradation pathways differ under aerobic and anaerobic conditions and decomposition is usually faster under anaerobic conditions. Depending on experimental conditions, physicochemical process (Probst and Tepe, 1969) or microbiological process (Parr and Smith, 1973) predominate. In the presence of ultraviolet radiations, trifluralin is rapidly photodecomposed. In addition, trifluralin can be extensively lost by volatilization depending on concentration, mode of application, and moisture content of the soil (Bardsley, Savage, and Walker, 1968). Volatilization was reduced in flooded soil conditions (Parr and Smith, 1973).

#### **5.4.2. Factors That Affect Pesticide Decomposition in Wetland Soils**

**5.4.2.1. Climatic Factors.** The loss of organic pesticides through processes involving volatilization, photodecomposition, and, more important, microbial degradation is expected to be more rapid under tropical and subtropical conditions than in temperate environment (Sethunathan, Adhya, and Raghu, 1982).

Higher temperature in tropical areas might favor both microbial and chemical decomposition. Gamma HCH was shown to decompose faster at 35°C than at 25°C in a flooded soil (Yoshida and Castro, 1970). High temperature decreases adsorption and favors desorption of pesticides, which may result in higher amounts of pesticides dissolved in soil water and faster dispersion (Guenzi and Beard, 1976).

Diurnal variations in light intensity and temperature can lead to marked variations in photosynthetic activity in floodwater, resulting in water pH changes marked as two pH units within a day. Floodwater pH changes favor chemical decomposition of pesticides as reported for carbofuran (Seiber et al., 1978; Siddaramappa et al., 1978). Carbofuran loss due to hydrolysis was over 700 times more rapid at pH10 than at pH7.

In rainfed ricefields, soils subjected to alternate periods of flooding and drying, resulting in successions of microflora dominated aerobic and anaerobic microorganisms, might provide conditions favorable for more extensive decomposition by microorganisms. Sethunathan (1972) showed that diazinon was hydrolyzed in flooded soils, but the ring portions of its hydrolysis products were open only under aerobic conditions following anaerobiosis.

**5.4.2.2. Anaerobiosis: Wetland Versus Upland Conditions.** The comparison of pesticide stability in wetland and upland conditions (Figure 5.3) often shows a longer persistence in nonflooded soils than in flooded soils (Watanabe, 1973a; Sethunathan and Siddaramappa, 1978). Among organochlorine insecticides, DDT, DDD, methoxychlor, and heptachlor degraded faster in flooded soil than in upland soil; DDD was found to accumulate in DDT-treated flooded soil; and endrin was degraded only in flooded soil (Castro and Yoshida, 1971). As summarized by Sethunathan, Adhya, and Raghu (1982), while gamma HCH persisted for at least two years in aerobic upland soils, it reached nonsignificant levels (less than 0.02 ppm) within twenty to thirty days in submerged soils even after high repetitive applications of a total amount of 48 kg ai within four successive cropping seasons.

The faster pesticide degradation in wetland soils is at least partly due to a relation between soil redox (Eh) and pesticide degradation. A study of the relationship between Eh and the rate of trifluralin degradation, using a system for controlling redox potential in soil suspensions, indicated that O<sub>2</sub> exclusion by soil flooding initiated rapid trifluralin degradation only when the Eh decreased below a critical range between +150 and +50 mV (Willis, Wander, and Southwick, 1974). Gamma and beta isomers of HCH decomposed rapidly in nonsterile soils capable of attaining redox potentials of -40 to -100 mV within twenty days after flooding (Siddaramappa and Sethunathan, 1975; Sethunathan et al., 1976). Degradation was slow in soils low in organic matter and in soils with very low

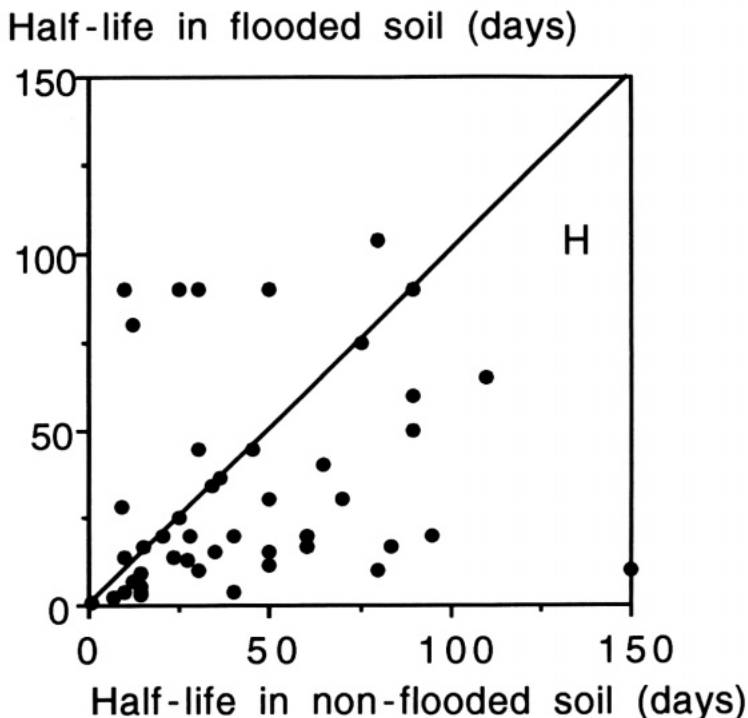


Figure 5.3. Stability of Thirty-Six Pesticides in Flooded and Nonflooded Soil

Source: Drawn from data by Agnihotri, 1978; Arita and Kuwatsuka, 1991; Castro and Yoshida, 1971; Ferreira and Raghu, 1981; Funayama, Uchida, Kanno, and Tsuchiya, 1986; Probst and Tepe, 1969; Probst et al., 1967; Rajaram and Sethunathan, 1976; Reddy and Sethunathan, 1983; Sethunathan, 1984; Sethunathan and Siddaramappa, 1978; Sethunathan and Yoshida, 1973c; Tomizawa, 1975; Tomizawa, Uesugi, Ueyama, and Yamamoto, 1976; Venkateswarlu, Gowda, and Sethunathan, 1977; Wang and Broadbent, 1973; Yoshida and Castro, 1970; Yoshida, 1975; Yoshida and Castro, 1975.

pH and positive Eh after several weeks of flooding (Sethunathan et al., 1976). A low or negative Eh also favored the degradation of DDT (Guenzi, Beard, and Viets, 1971), endrin (Gowda and Sethunathan, 1977), and toxaphene (Parr and Smith, 1976).

Pesticide degradation can be very rapid in prereduced soils as shown with parathion which exhibited 48 to 86 percent disappearance when shaken for five seconds with reduced soil (Wahid, Ramakrishna, and Sethunathan, 1980).

Sethunathan et al. (1980) suggested that redox potential, reducing capacity and certain reduction reactions, assayed, for example, in terms of nitrate disappeared or reduced iron formed, could be used as simple and suitable indicators of the pesticide-degrading capacity of anaerobic systems. Dehydrogenase activity

is well pronounced in predominantly anaerobic flooded soil and may have the obvious advantage over the  $^{14}\text{CO}_2$  evolution technique as an assay for the pesticide-degrading capacity of anaerobic systems.

Organic matter incorporation, which hastens the drop in Eh favors pesticide degradation (see Section 5.4.2.3). However, some pesticides may reduce the drop in Eh of rice soils, as observed with HCH by Pal, Misra, and Sethunathan (1980).

Sethunathan and Siddaramappa (1978) suggested that the alternate oxidation and reduction processes in intermittently flooded soils may favor degradation of pesticides. Brahmaprakash, Reddy, and Sethunathan (1985) observed that the degradation of anaerobically unstable HCH isomers in the rice rhizosphere was not retarded by the possible aeration of a flooded soil by roots.

Some reports indicate no difference in degradation in upland and flooded conditions as observed for chlordane and dieldrin, which persisted for at least three months in both upland and submerged conditions (Castro and Yoshida, 1971). Similar findings have been reported for carbaryl (Rajagopal, Rao, Nagendrapa, and Sethunathan, 1984).

In some cases a longer persistence of pesticides was observed under flooded conditions than under upland conditions, as for benthocarb (Nakamura, Ishikawa, and Kuwatsuka, 1977), phorate (Walter-Echols and Lichtenstein, 1978), aldrin (Castro and Yoshida, 1971) and molinate, oxidation of which drastically decreases as Eh becomes lower than 100 mV (Deuel, Turner, Brown, and Price, 1978). Pesticide losses by volatilization can also be retarded in flooded environments, as shown for trifluralin (Parr and Smith, 1973).

The mechanisms of degradation-transformation differ in wetland and upland conditions; the same compound may be degraded through different pathways depending on the redox conditions. For example, trifluralin degrades by a pathway involving sequential dealkalination of propyl groups in aerobic conditions, and by a pathway involving initial reduction of the nitro groups in anaerobic conditions (Parr and Smith, 1973). In flooded conditions, the process of reductive dechlorination has been demonstrated for DDT, hydrolysis for diazinon and parathion, and nitro-group reduction for parathion. Dehydrochlorination (DDT), ring cleavage (IMHP), and epoxidation (aldrin and heptachlor) are apparently blocked or less favored in oxygen-depleted flooded soil (Sethunathan, 1972; Hill, 1978).

**5.4.2.3. Soil Factors.** The degradation rate of a given pesticide can markedly differ among soils. In a study of the fate of endrin in eight soils from India, Gowda and Sethunathan (1976) found percentages of persistence twenty-five days after application to average sixty-two, ranging from twenty-three to ninety-nine. A laboratory comparison of the degradation rate of  $^{14}\text{C}$ -labeled pyrazoxyfen in five rice soils from Japan under upland (50 percent of the maximum water-

holding capacity) or flooded (covered with one cm of water) conditions showed a faster degradation in the mineral soils (half-life: three to five days) than in the humic volcanic ashes (half life: five to thirty-four days) (Arita and Kuwatsuka, 1991). Among soil properties influencing pesticide degradation, pH and organic matter content are most often reported, but cation-exchange capacity, C/N ratio, and water-holding capacity are also involved (Arita and Kuwatsuka, 1991). On the other hand, no marked differences in the degradation rates of benthocarb were observed among three soils differing by their clay content (5 to 23 percent), pH (5.2 to 6.1), total C (1.8 to 7.9 percent) and CEC (14 to 40) (Nakamura, Ishikawa, and Kawatsuka, 1977).

The degradation of some pesticides is affected by soil pH. Sethunathan, Adhya, and Raghu (1982) presented several examples indicating that both alkaline and acidic conditions could enhance the decomposition of specific pesticides or groups of pesticides. They indicated that organophosphates and carbamates are more affected by soil pH than organochlorine insecticides. Aldicarb degradation was rapid in neutral soil, much slower at pH near 6.0, and greatly retarded at pH lower than 5.6 (Read, 1987).

The breakdown of pesticides in soil with low pH may be retarded because they have a high anion exchange capacity and therefore would tend to adsorb more pesticides than soils of high pH do (Edwards, 1974). Bailey, White, and Rothberg (1968) concluded that all organic herbicides tested were adsorbed more by an highly acid clay soil than a near neutral soil. Microbial degradation of carbofuran in these soils was the slowest in soil with the lowest pH (Siddaramappa, Tirol, and Watanabe, 1979).

Several reports indicate that pesticides are degraded slowly in acid sulphate soils. This was observed for gamma and beta BHC (Siddaramappa and Sethunathan, 1975), endrin (Gowda and Sethunathan, 1976), and carbofuran (Venkateswarlu, Gowda, and Sethunathan, 1977). In an acid sulfate soil, carbofuran exhibited a lag of about twenty days before degradation started (Venkateswarlu and Sethunathan, 1984). Carbaryl was more persistent in an acid sulfate soil (pH 3.7) than in other acid soils (pH 4.2 to 4.8) (Gill and Yeoh, 1980). Low pesticide degradation rates in acidic soils, particularly in acid sulphate soils, are commonly attributed to low bacterial activity. However, other factors may also be involved. Wahid and Sethunathan (1979) observed that hydrogen sulphide, the end product of sulfate reduction, which is frequent in such soils, was involved in the degradation of parathion.

Liming flooded-anaerobic acid soils was reported to cause a rapid conversion of DDT to TDE (Parr and Smith, 1974) but had no significant effect on the degradation of BHC (Siddaramappa and Sethunathan, 1975) and endrin (Gowda and Sethunathan, 1976).

Soils rich in organic matter often have a high microbiological activity, which

favors pesticide degradation. Organochlorine insecticides were found to degrade faster in soils with high organic matter content (Castro and Yoshida, 1971). In acid rice soils of Kerala, India, Sethunathan (1973b, 1973c) observed that parathion degraded faster in the soil that had a higher organic matter content. However, organic matter was found to be the most prominent soil factor conditioning sorption of pesticides in soil (see Section 5.5.1).

Several reports show that organic matter incorporation, which increases microbial activity and hastens the drop in redox potential in flooded soils, favors pesticide degradation. This was observed for straw incorporation (Adhya, Sudhakar-Bark, and Sethunathan, 1981a; Chopra and Magu, 1986; Gowda and Sethunathan, 1976; Lee, 1981; Siddaramappa and Sethunathan, 1975; Venkateswarlu and Sethunathan, 1979) as well as for green manure incorporation (Fereira and Raghu, 1981; Parr and Smith, 1973). However, Castro and Yoshida (1974) observed this effect only when soil organic matter was low. Applications of rice straw to a flooded soil inoculated with parathion-hydrolysing enrichment culture inhibited the hydrolysis of the insecticide; the inhibitory factor was not formed in rice straw-amended flooded soils incubated at 50 and 75 percent moisture levels (Rajaram, Rao, and Sethunathan, 1978).

**5.4.2.4. Water Management and Method of Pesticide Application.** In uplands, pesticide remains at the soil surface until cultivation or watering incorporates them into the soil. In wetlands, a faster dilution can be expected, with variations depending on solubility and surfactants used. Pesticides can be sprayed, applied in the floodwater, incorporated into the soil, or used for dipping rice seedling at transplanting. Water management and the method of pesticide application might affect pesticide persistence and decomposition with regard to dilution and movements in the soil, but little information is available on this aspect.

The persistence of carbofuran in the soil was increased to about sixty days, and its concentrations in floodwater reduced by its incorporation at a depth of about 3 cm (Siddaramappa, Tirol, and Watanabe, 1979) or by its placement in gelatin capsules in the root zone (Siddaramappa and Seiber, 1979). A much faster dissipation was observed when seedling roots were soaked in carbofuran solution (Seiber et al., 1978). Similar observations were made for chlormediform (Aquino and Pathak, 1976).

Pesticide applied to the rice canopy is less subjected to microbial decomposition than when applied to the soil; however it has been shown that microorganisms present in the phyllosphere may contribute to pesticide decomposition (Rajagopal, Brahma Prakash, and Sethunathan, 1984).

**5.4.2.5. Pesticide Concentration.** Pesticides applied at high concentrations seem to decompose more slowly than when applied at low concentrations.

Trifluralin at 200 ng/ $\mu$ l had a negligible rate of photodecomposition after forty days, compared with a half-life of about twenty days when applied at concentrations between 1 and 0.1 ng/ $\mu$ p1 (Parr and Smith, 1973). Molinate also persisted longer in plots treated at an excessive rate (Deuel, Turner, Brown, and Price, 1978).

**5.4.2.6. Effects of Combined Pesticides.** When two pesticides are applied simultaneously, one can inhibit the microorganisms responsible for the degradation of the other or modify the physicochemical conditions in a way that reduces its degradation. This was observed for *Clostridium rectum*, a BHC decomposer isolated from a ricefield soil, whose growth and BHC decomposing ability were inhibited by pentachlorophenol (Ohisa and Yamaguchi, 1978b). Similarly, benomyl applied in combination with parathion increased the persistence of generally short-lived parathion by inhibiting microbial hydrolysis and nitro group reduction (Sudhakar-Barik and Sethunathan, 1979). Benomyl also inhibited nitrification, iron reduction and the drop in the redox potential in the flooded soil: after twenty-four days of incubation Eh was  $-20\text{mV}$  in the control and  $+100\text{mV}$  in the treatment receiving 5 ppm benomyl, which contributed to reduced parathion decomposition (Sethunathan et al., 1980). In a model ecosystem, combination of methyl parathion with atrazine substantially decreased the degradation of both pesticides in the roots of rice and increased their persistence in water and soil (Au, 1980). However, soil incorporation of benthocarb with simetryne, CNP or propanil had no significant effect on the degradation rate (Nakamura, Ishikawa, and Kuwatsuka, 1977) and the persistence of parathion was not affected by simultaneous addition of HCH or 2,4-D (Sudhakar-Barik and Sethunathan, 1979).

**5.4.2.7. Effect of Fertilizers.** N fertilizer application may affect pesticide persistence but data are too scarce to draw general conclusions. The addition of ammonium nitrogen to a mineral medium retarded the degradation of the nitrogenous pesticide carbaryl by soil enrichment cultures (Rajagopal, Brahma Prakash, and Sethunathan, 1983). Ammonium sulphate and urea increased the persistence of carbaryl in a flooded laterite soil with a low nitrogen content (0.04 percent), but not in an alluvial soil with a higher nitrogen content (0.11 percent) (Rajagopal and Sethunathan, 1984). Applications of potassium nitrate or ammonium sulphate to a flooded soil inoculated with parathion-hydrolysing enrichment culture, inhibited the hydrolysis of the insecticide (Rajaram, Rao, and Sethunathan, 1978). Degradation of disulfon and phorate in soil alone was also slightly slower than when fertilizer was added; however, *in situ* degradation was faster when fertilizer was applied because of a better plant growth in the treated plots (Agnihotri, 1978). The application of ammonium sulphate and urea showed little

influence on the persistence of carbofuran in a Philippine flooded rice soil (Maahas clay) with a high nitrogen content (Siddaramappa and Seiber, 1979).

**5.4.2.8. Effect of Repeated Applications on Decomposition.** Repeated application of the same pesticide has been reported to enhance the growth of the related specific decomposing microorganisms and cause the rapid inactivation of the pesticide. A second application of gamma-BHC to a non-sterilized soil fifty-five days after the first one showed a faster degradation of the pesticide: half life was about eighteen days at the first application and twelve days at the second application (Raghu and MacRae, 1966). Diazinon persisted for about fifteen days in a flooded soil (pH 6.6) that had been treated previously with this insecticide; but it persisted for about sixty days in a soil that had never been exposed to diazinon (Sethunathan, 1972). Two successive annual applications of aldicarb, as subsurface band-in-row treatments at 4 kg ai/ha in the same field, resulted in the development of microorganisms that rapidly broke down aldicarb and accelerated its degradation in soil and water (Read, 1987). In a laboratory experiment with enrichment cultures from soil-water mixtures, the time needed for the breakdown of 50 ppm aldicarb applied repeatedly was eighty days for the first application, fourteen days for the fifth application, and three days for the tenth application (Read, 1987).

Several bacteria having the ability to degrade a given pesticide were isolated from soils or water of fields previously treated with the same pesticide. A *Flavobacterium* sp., isolated from water of a diazinon-treated ricefield, had exceptionally high capability to metabolize diazinon as its sole carbon source (Sethunathan, 1972; Sethunathan and Pathak, 1971). Similarly, Sudhakar-Barik, Siddaramappa, and Sethunathan (1976) isolated a *Pseudomonas* sp. and *Bacillus* sp. that were able to decompose nitrophenols from parathion-amended flooded soil. A substantial portion (23 percent for *Pseudomonas* sp. and 80 percent for *Bacillus* sp.) of radioactivity applied as p-nitrophenol was accounted for as  $^{14}\text{CO}_2$  at the end of a seventy-two-hour period. Watanabe (1973b, 1977) isolated PCP-decomposing and PCP-tolerant bacteria from soils and observed a 1,000-fold difference in the number of PCP-decomposing microorganisms between treated and untreated soil (Watanabe, 1978).

Enrichment cultures from soil repeatedly treated with pesticide have been used to isolate carbofuran-degrading bacteria, but even these cultures exhibited a lag in the degradation of carbofuran (Rajagopal, Brahmaprakash, and Sethunathan, 1983).

However, there are also reports indicating that repetitive application of pesticides did not lead to the buildup of the degrading microflora. This was reported in laboratory experiments with carbofuran (Siddaramappa et al., 1978; Venkateswarlu and Sethunathan, 1978) and benthocarb (Nakamura, Ishikawa,



and Kuwatsuka, 1977). Also Ohisa and Yamaguchi (1978a, 1978b) observed that enrichment of soil populations of *Clostridium rectum* (a bacterium isolated from ricefield soil that degrades BHC by a cometabolic process) was not caused by BHC application but by the addition of peptone.

Repeated application of pesticide has also been reported to cause changes in the metabolic pattern of pesticide decomposition (Sudhakar-Barik, Wahid, Ramakrishna, and Sethunathan, 1979). The principal metabolic pathway for the insecticide parathion shifted from nitro group reduction to hydrolysis on the repeated additions of parathion to a flooded soil. A similar result was obtained when p-nitrophenol, a parathion hydrolysis product, was applied, showing the enrichment of a population capable of degrading a parent molecule on application of the primary product of its metabolism. Both nitro group reduction and hydrolysis are cometabolic reactions; the buildup of parathion-hydrolysing micro-organisms after parathion additions was at the expense of the product of the primary cometabolic hydrolysis, p-nitrophenol (Sethunathan et al., 1980).

Changes in degradation pathways can be detrimental. For example, benthocarb is generally detoxified by hydrolysis, but its repeated application to flooded soil favored the multiplication of anaerobic bacteria that decompose benthocarb by reductive dechlorination, resulting in the formation of a phytotoxic compound detrimental to rice (Moon and Kuwatsuka, 1984).

## 5.5. Pesticide Movements in Wetland Ricefields

After application, pesticides begin to disappear from the target area either by physical movement by the action of air or water, or by degradation (Taylor and Spencer, 1990).

Pesticide movements include adsorption/desorption by soil, volatilization, diffusion, percolation, runoff, and adsorption by plants and animals.

### 5.5.1. Adsorption-Desorption by Soil

Adsorption-desorption is a dynamic process in which molecules are continually transferred between the bulk liquid and solid surface (Koskenen and Harper, 1990). Adsorption is the binding of the pesticide molecules by the surface of the treated soil, whereas desorption implies detachment of the molecules to the liquid medium. The strength of the adsorption bond depends on the properties of both the pesticide and the soil. Adsorption-desorption of pesticides largely determines the quantity of pesticide available for biological interactions in soil and water. The organic matter content and the amount of colloidal materials in

the soil are major factors influencing pesticide sorption and persistence in soil. Higher amounts of colloidal materials increase persistence due to more adsorption surface area.

The classical method for studying sorption has been to shake  $^{14}\text{C}$ -labeled pesticide with a soil suspension for a short time (1 to 2 hrs) and to measure supernatant pesticide after centrifugation. Using this method, Sethunathan et al. (1980) found sorption accounting for 40 to 95 percent of applied pesticides. Between 60 and 70 percent of carbofuran added to three soils was recovered immediately after mixing the pesticide with the soil (Venkateswarlu, Gowda, and Sethunathan, 1977). Carbofuran recovery just after mixing with an alluvial soil was 57 percent in the control and 52 percent when the soil was enriched with 0.5 percent straw (Venkateswarlu and Sethunathan, 1979). Empirical relationships have been established by some researchers between extent of adsorption and organic matter content. A logarithmic relation between parathion sorption and organic matter content was reported by Wahid and Sethunathan (1978). Comparing rice soils of Tamil Nadu, India, Saivaraj and Venogupal (1978) found that mephosfolan persisted longer in clay soil containing a higher organic matter than in sandy soils.

In soils poor in organic matter, free iron oxide and clay might be related to pesticide sorption but the correlation has not been consistently observed. The correlation was significant with parathion and gamma BHC, but not with alpha BHC (Sethunathan et al., 1980).

Adsorption may also take place during the metabolism of pesticides in flooded soils. Katan, Fuhremann, and Lichtenstein (1976) reported that the decrease of extractable  $^{14}\text{C}$ -parathion residues in flooded soils over one month was associated with a near proportional increase of unextractable residues; aminoparathion, which resulted from the reduction of parathion, was absorbed about thirty times more than parathion itself.

### 5.5.2. *Volatilization*

Volatilization is the process by which applied pesticides are turned into vapor phase and subsequently lost into the atmosphere. Volatilization increases with increased pesticide concentration. The process is most active when the pesticide is applied on the surface of water or on wet soil, and at the beginning of the crop cycle when the rice canopy is not closed and the land is largely exposed. Incorporation of the pesticide immediately after application, even to a shallow depth, or application on dry soil will reduce volatilization losses.

Volatilization is a major cause of pesticide loss from target areas, particularly when they are applied to the surfaces of soils or plants. Volatilization loss often

exceeds that by chemical degradation. The effective life of pesticides in many instances may be limited by the rapid disappearance from the target area by volatilization and other means, resulting in the need for repeated applications, particularly in moist warm conditions of the tropics (Taylor and Spencer, 1990).

Soderquist, Bowers, and Crosby (1977) analyzed molinate and its degradation products at sub-ppm levels in water, soil, and air samples collected from a commercially treated field and showed that volatilization of molinate from water was the primary mode of dissipation, although photodecomposition products were present in field water. Substantial volatilization loss was also reported for HCH tested in the laboratory: 67 percent of  $^{14}\text{C}$ -gamma HCH was lost when applied to rice field water alone, 43 to 68 percent when applied to submerged soils, and 12 percent when applied to nonsubmerged soil (Siddaramappa and Sethunathan, 1976). Field measurements by Seiber, McChesney, Sanders, and Woodrow (1986) showed that volatilization was highest on the day of application and decreased rapidly. Volatilization rates varied within large limits depending on the nature of the pesticide. They reported values in  $\text{ng}/\text{cm}^2/\text{ha}$  on the day of application at 1.3 for 4-Chloro-o-cresol, 4.4 for MCPA, 37 for thiobencarb, and 575 for molinate.

Gaseous exchanges that take place between the soil and the atmosphere through the rice may favor losses of pesticides by volatilization, as observed for carbofuran. Siddaramappa and Watanabe (1979) observed by radiography a fairly rapid translocation of carbofuran, in significant amounts, to the foliage of rice seedlings after its application to flooded soil.

### 5.5.3. *Diffusion*

Diffusion is the process of fluid flow due to concentration gradient. Diffusion takes place in both gaseous and liquid phases of pesticides applied on ricefields. The process is governed by Fick's law, which states that the rate of diffusion in a given direction is proportional to the concentration gradient in that direction. Decreasing bulk density or increasing temperatures raises coefficient (Ehlers, Farmer, Spencer, and Letey 1969). Pesticides applied on ricefields are in a state of continuous flux due to the diffusion process, even if not by other forces, in nature's equilibrium-seeking behavior. Diffusion may control volatilization of pesticides.

When a pesticide is applied on dry soil or plant canopy, its volatilization will depend on the upward diffusion to the open surface as a concentration gradient is established (Taylor and Spencer, 1990). When a pesticide is incorporated into the soil by cultivation, the rate at which it volatilizes is controlled by its movement through the body of the soil to the overlying air. Because the diffusion path length to the surface is longer for incorporated pesticide, compared to the

condition when the chemical is applied on the top of the soil, volatilization of incorporated pesticide will be greatly restricted.

In an experiment where [ $^{14}\text{C}$ ] phorate was mixed with soils prior to soil submersion, residues were readily released from submerged soils into water, amounting to 45 percent of applied radiocarbon during the first three days after flooding. After a two-week incubation period as much as one-half of the radiocarbon applied to the soil was recovered from the water. Phorate was the principal compound recovered from submerged soils where it accounted for approximately 70 percent of the total residues recovered. Phorate sulfoxide was the major metabolite present in the water (Walter-Echols and Lichtenstein, 1978).

#### 5.5.4. *Percolation*

Percolation is the vertical downward movement of water due to gravitational force. With percolating water, pesticides dissolved in water or absorbed by particulate matters in the water move from the point of application to a deeper horizon of the soil profile. Through this process the chemicals can reach the water table and then move with the water table. Water-soluble formulations move faster in soil than the oil-soluble formulations. Adsorption of pesticides by soil reduces the effective movement of pesticides in the soil profile, which occurs significantly in soil that is rich in organic matter. That is why pesticides applied on ricefields may take a long time, even years, before they can be traced in deeper layers of the soil.

Pesticides would leach more readily in sandy soils than in clay soils because in sandy soils adsorption of pesticides is less and percolation rate higher. Puddling in lowland ricefields retards the transport of pesticides to the subsoil because it creates a less permeable soil in the plowed zone. Ramanand, Sharmila, and Sethunathan (1988) recovered a substantial amount of carbofuran from the leachates of unpuddled ricefields at both the 15 cm and 30 cm soil depths, but in puddled soil the mobility of carbofuran was found limited up to 15 cm and almost negligible at the 30 cm depth. Most pesticides would probably persist in the subsoil, but their accumulation would be a potential source of groundwater contamination in the long run. Some authors have however assumed that pesticides would not leach to groundwater except under rare circumstances (Hallberg, 1987).

#### 5.5.5. *Runoff*

Runoff, the lateral movement of water on land surface, may be responsible for pesticide transport away from the target area. Runoff results from excessive application of irrigation water or rainfall or from draining of the field to get rid of the water. Pesticides in runoff water from ricefields may be both in suspension

and adsorbed in colloidal particles. The time interval between the application of the pesticides and the rainfall or applied irrigation sufficient to produce runoff has significant effect on the amount of pesticide transported by runoff. Rainfall would wash off pesticide sticking to canopy and other parts of the plant body and move it to the standing water or soil surface, from where it may be transported by runoff.

Runoff water from ricefields is ultimately discharged into large bodies of water such as lake, rivers, or sea. Therefore, the contamination of freshwater bodies from pesticides transported by runoff is a matter of concern. Many previous studies have documented the serious effects of toxicity developed from agricultural pesticides on aquatic life, especially fish (see Chapter 8).

Very few studies have been conducted to quantify pesticide losses through runoff from ricefields. At the IRRI experimental farm organophosphates and carbamates in runoff water were found to be on the average at 1.0 ppb, with a range of 0 to 20.0 ppb (IRRI, 1988), which are considered low. Several studies in the United States showed that pesticide losses through runoff from field crops are small. Wauchope (1978) reported that for the majority of commercial pesticides total losses of pesticides in runoff water are 0.5 percent or less of the amount applied, unless severe rainfall occurred within one to two weeks after application. Willis, Rogers, and Southwick (1975) reported that the highest concentration of runoff loss over a three-year period of the applied diuron, linuron, fenac, and trifluralin were 0.12 percent, 0.30 percent, 2.90 percent, and 0.05 percent, respectively. These values were present in runoff water associated with rainstorms that occurred soon after application.

#### *5.5.6. Absorption by Crop or Animals*

Pesticides applied to protect a crop can be absorbed by the crop itself, which is subsequently removed from the field on harvest, and thus they can enter the food chain. Ricefield-residing flora and fauna can also absorb the chemicals and contribute to through natural movements or harvest. These aspects are covered in the next section.

### **5.6. Persistence and Partition in the Ricefield Ecosystem**

#### *5.6.1. Persistence*

The term persistence is used to express both the duration of the chemical's efficacy and undesirability; i.e., persistence for less than the desired time may

result in poor efficiency, while persistence beyond this time may lead to residue problems (Saltzman and Yaron, 1986). "Persistence time" is the time required for pesticide concentration to decline to 10 percent of the initial value. "Half-life" describes the dissipation rates, which is about 0.3 of the persistence time (Wauchope, 1978). Table 5.2 summarizes the half-life of pesticides in rice soils under different conditions. The half-life is often shorter under flooded conditions; soil sterilization often markedly increases half-life, showing the relative importance of microbial decomposition of pesticides.

### 5.6.2. *Partition in the Components of the Ricefield Ecosystem*

The relative extents of pesticide partition in the components of the ecosystems—in air, water, soil, and vegetation—vary with the mode of application and the nature of the pesticides, but soil and water invariably account for most of the pesticide in ricefields. Ross and Sava (1986) followed the fate of two herbicides, granular thiobencarb and molinate, broadcast in ricefields for thirty-two days after application. Maximum thiobencarb concentrations in air, water, soil, and vegetation were 1.4 ug/m<sup>3</sup>, 576 ug/L, 3860 ug/kg, and 1750 ug/kg, respectively. The mass balance budget indicated that thiobencarb was predominantly distributed between water (34 percent) and soil (43 percent), and only less than 1 percent was located in air and vegetation. Maximum molinate concentrations in air, water, soil, and vegetation were 48 ug/m<sup>3</sup>, 3430 ug/L, 2210 ug/kg, and 918 ug/kg, respectively. The mass balance budget indicated that as much as 81 percent of the molinate applied was dissolved in water followed by soil (10 percent), air (9 percent), and vegetation (less than 1 percent). Partitioning of these herbicides in the field was closely related to their physicochemical properties.

Isensee, Kaufman, and Jones (1982) used a rice microcosm to study the fate of 3,4-dichloroaniline (DCA), a major metabolite of the herbicide propanil (3',4'-dichloropropionanilide), in ricefields. Soil treated with 10 ppm DCA was placed in glass chamber, planted to rice, and flooded when the rice reached the two-leaf stage. After flooding, four species of aquatic organisms (algae, snail, daphnid, fish) were added. The concentration of DCA and metabolites in soil, rice, water, and aquatic organisms was determined over time. A maximum of 2.8 percent of the total radioactivity applied to soil desorbed or leached into water. DCA recovered from water decreased from 12 to 1 percent of the total radioactivity in water between one and thirty days after flooding. Between 10.5 and 18.5 percent of the radioactivity remaining in soil at the end of the experiments was extractable. Of the radioactivity recovered, between 5 and 11 percent was DCA, and up to 6 to 19 percent was 3,3', 4,4'-tetrachloroazobenzene (TCAB), the percentages

Table 5.2. Half-Life (Days) of Pesticides Tested in Wetland Rice Soils

| <i>Pesticide</i> | <i>Half-Life<br/>(Days)</i> | <i>References</i>                                                                     |
|------------------|-----------------------------|---------------------------------------------------------------------------------------|
| 2,4,5,-T         | 17–45                       | —Yoshida, 1975                                                                        |
| 2,4-D            | 28–36                       | —Yoshida, 1975                                                                        |
| AlphaBHC         | 22–42                       | —MacRae, Raghu, and Castro, 1967; Fereira and Raghu, 1981                             |
| Amiprophos       | 10                          | —Tomizawa, 1975                                                                       |
| Basagran         | 3                           | —Higashi and Crosby, 1987                                                             |
| Benefin          | 4                           | —Probst and Tepe, 1969                                                                |
| Bentazon         | 3                           | —Higashi and Crosby, 1987                                                             |
| Benthiocarb      | > 80                        | —Nakamura, Ishikawa, and Kuwatsuka, 1977                                              |
| BetaBHC          | 22–65                       | —MacRae, Raghu and Castro, 1967; Fereira and Raghu, 1981                              |
| BHC              | 20                          | —Yoshida and Castro, 1970                                                             |
| Buprofezin       | 104                         | —Funayama, Uchida, Kanno, and Tsuchiya, 1986                                          |
| Butachlor        | 1–12                        | —Chen, 1980                                                                           |
| Carbaryl         | 14–49                       | —Gill and Yeoh, 1980; Sethunathan, 1984                                               |
| Carbofuran       | 19–70                       | —Siddaramappa, Tirol, and Watanabe, 1979; Venkateswarlu, Gowda, and Sethunathan, 1977 |
| Chlomethoxynil   | 15                          | —Matsunaka and Kuwatsuka, 1975                                                        |
| Chlordane        | > 90                        | —Castro and Yoshida, 1971                                                             |
| CNP              | 15                          | —Matsunaka and Kuwatsuka, 1975                                                        |
| DCNA             | 5–30                        | —Wang and Broadbent, 1973                                                             |
| DDT              | > 45                        | —Castro and Yoshida, 1971                                                             |
| DeltaBHC         | 32–50                       | —MacRae, Raghu, and Castro, 1967; Fereira and Raghu, 1981                             |
| Diazinon         | 13–15                       | —Sethunathan and MacRae, 1969;<br>—Sethunathan and Siddaramappa, 1978                 |
| Disulfoton       | 25                          | —Agnihotri, 1978                                                                      |
| Endrin           | 7–55                        | —Gowda and Sethunathan, 1976                                                          |
| GammaBHC         | 12–40                       | —MacRae, Raghu, and Castro, 1967; Raghu and MacRae, 1966<br>—Fereira and Raghu, 1981  |
| Heptachlor       | 75–90                       | —Castro and Yoshida, 1971                                                             |
| Hinosan          | 4                           | —Rajaram and Sethunathan, 1976                                                        |
| Isoxathion       | < 20                        | —Nakagawa, Ando, and Obata, 1975                                                      |
| Kitazin          | 14                          | —Tomizawa, Uesugi, Ueyama, and Yamamoto, 1976                                         |
| Metoxychlor      | > 90                        | —Castro and Yoshida, 1971                                                             |
| Metoxychlor      | 90                          | —Castro and Yoshida, 1971                                                             |
| Molinate         | 2–96                        | —Deuel, Turner, Brown, and Price, 1978; Higashi and Crosby, 1987                      |
| Nitrofen         | 11                          | —Matsunaka and Kuwatsuka, 1975                                                        |
| Ordram           | 6                           | —Higashi and Crosby, 1987                                                             |
| Parathion        | 4–23                        | —Reddy and Sethunathan, 1983; Sethunathan, 1973b<br>—Sethunathan and Yoshida, 1973c   |
| PCNB             | 20                          | —Wang and Broadbent, 1973                                                             |
| PCP              | 30                          | —Matsunaka and Kuwatsuka, 1975                                                        |
| Phorate          | 20                          | —Agnihotri, 1978                                                                      |
| Picloram         | 60                          | —Yoshida, 1975                                                                        |
| Propanil         | 1                           | —Matsunaka and Kuwatsuka, 1975                                                        |
| Pyrazoxyfen      | 4–34                        | —Arita and Kuwatsuka, 1991                                                            |
| Sevin            | 13                          | —Sethunathan and Siddaramappa, 1978                                                   |
| Swep             | 2                           | —Matsunaka and Kuwatsuka, 1975                                                        |
| Trifluralin      | 10                          | —Probst et al., 1967                                                                  |

being dependent on exposure time. Rice accumulated 0.5 percent or less of the total radioactivity in soil. Only 35 to 55 percent of the accumulated radioactivity was extractable. Very small amounts of radioactivity were accumulated by aquatic organisms.

Kearney, Smith, Plimmer, and Guardia (1970) determined propanil and propanil residue (3,3', 4,4'-tetrachloroazobenzene: TCAB) in rice soils with known histories of propanil application. Concentration of propanil and occurrence of TCAB decreased with increasing time and depth in soil. For total propanil applications ranging from 7 to 13.5 kg/ha, concentrations of propanil in the upper 10 cm of soil were around 0.1 to 0.2 ppm two to six weeks after the last application and lower than 0.02 ppm one year after application. Concentrations of TCAB were between 0.16 and 0.01 ppm two and six weeks after the last application and lower than 0.02 ppm one year after application.

A study of the fate of phorate in a soil-water-plant system using *Elodea* as plant component showed that fourteen days after application and thorough mixing with soil, soil, water, and plants contained 32, 39, and 17 percent of the applied radiocarbon, respectively (Walter-Echols and Lichtenstein, 1978).

In a microcosm study of the fate of  $^{14}\text{C}$ -lindane on rice-fish agricultural system, the distribution of  $^{14}\text{C}$  residues among the constituents of the model ecosystem was studied for ninety days (Mostafa, El-Arab, and Zayed, 1987). Lindane accumulated in fish and rice plant to a considerable extent. The insecticide was found to be readily absorbed by the roots and translocated to all parts of the rice plant. The peak level in the shoots (26 ppm) and roots (105 ppm) of plants was reached within three weeks. Concentration in the soil decreased from 1.8 ppm at seven days to 0.7 ppm at ninety days. Concentration in the fish reached a maximum after thirty days (90 ppm) and decreased to 40 ppm at ninety days. The data also showed a relatively low biodegradability of lindane in fish and rice plants.

### 5.6.3. *Absorption by Rice*

Pesticides in the food chain is a matter of serious concern. However, pesticide concentrations in rice grains have not been reported to reach a serious level from normal applications of pesticides. Tejada and Magallona (1986) found that of the seven pesticide formulations used, carbofuran and chlorpyrifos residues translocated to rice harvest but in levels that have no toxicological significance.

Rice seed, plant, and soil samples from the provinces of Iloilo, Bulacan, Nueva Ecija, the Mountain Province, and Palawan in the Philippines were analyzed for the presence of the four BHC isomers and DDT. Low levels of the four BHC isomers were detected in all the samples. The plants generally had a



higher BHC content than the soil. The amounts of BHC found in the grain and hull of rice were below the tolerance limit set by the United States Food and Drug Administration. DDT and its metabolites were identified in Palawan and the Mountain Province. The presence of DDT in the samples could have been due to the contamination from the DDT sprayed for malaria control in the dwelling places where the rice was stored (Del Rosario and Yoshida, 1976).

Seiber et al. (1978) found that residues of carbofuran or its carbamate metabolites in rice plants, from fields treated by soil incorporation or root-zone placement, did not exceed the 0.2 ppm tolerance allowed in whole grains by the United States Environmental Protection Agency standards. Residues above 0.2 ppm were found only in whole grains from plants that received six broadcast application of carbofuran at fourteen-day intervals throughout the growing season. Combined residues of carbofuran and 3-hydroxycarbofuran were less than 0.2 ppm in the grain from rice treated four times at twenty-day intervals. Thus, carbofuran underwent appreciable translocation to rice grain only after frequent or high-dosage applications that continued well into the second half of the growing season (Seiber et al., 1978).

Lee and Ong (1983) reported significant levels of lindane in rice grains collected from warehouse and milling plants. Up to 80 percent of the residues could be removed by repeated washing with water, a practice used before rice is cooked. Boiling further broke down the residues. Lindane was present in only trace amounts in farmers' rice although the chemical had been used in ricefields to control insect pests.

#### 5.6.4. *Absorption by Plants and Animals*

In some parts of Asia a wide range of edible plants and animals, including fish, are collected from ricefields for human consumption (Heckman, 1979).

Whereas bioconcentration of pesticides in the various elements of the food chain is a major topic of interest in pesticide studies, little attention has been paid to this aspect in ricefield studies. The few available data refer to pesticide accumulation *in vitro* by cyanobacteria common in ricefields (Das and Singh, 1977; Kar and Singh, 1979). However data from freshwater environments have demonstrated the ability of microalgae to accumulate pesticides (Wright, 1978). The consequences of this bioconcentration could be particularly important in integrated rice-aquaculture systems.

Tejada and Magallona (1986) also found that aquatic plant "kangkong" (*Ipomoea aquatica*), when grown in water containing 0.13 mg/liter of carbofuran, rapidly absorbed carbofuran. This is typical of systemic insecticides broadcast into floodwater as granules which would penetrate the root zone and be subsequently

taken in by plants. Pesticide residues in “kangkong” were within acceptable daily intake level set for carbofuran by FAO/WHO (1977). The authors also showed that when carbofuran-contaminated rice leaves were fed to lactating goats for seven consecutive days, 77 percent of the dose was rapidly excreted in urine and very little was eliminated in feces (1 percent) and milk (0.5 percent). Residues were found in different tissues of goats but they were mostly nontoxic metabolites.

Certain aquatic animals have been reported to retain (bioaccumulate) pesticides in concentrations many times more than the concentrations in water. Bioaccumulation as a process is of concern in relation to pesticide toxicity in aquatic food. In their study of the fate of selected pesticides in rice-fish and livestock farming, Tejada and Magallona (1986) found carbofuran residues in fish at harvest, concentrated most in entrails, then in fillet and least in head but the concentrations were below the maximum acceptable limit set for meat (0.05 mg/kg). Similar findings were reported by Argente, Seiber, and Magallona (1977) for carbofuran and Zulkifli, Tejada, and Magallona (1983) for chlorpyrifos.

A pesticide residue trial in a small scale rice-fish culture showed that fish and snails were able to accumulate carbofuran residues respectively 100 and 10 times more than the concentrations of residues in the water (Tejada and Magallona, 1986).

## 5.7. Environmental Contamination

Pesticides may be introduced directly into the environment in a liquid phase, as a dispersion or solution, or in the solid phase—as a powder, microcapsule, or granule. Sprays are directed to the foliage or the soil. Solids are applied directly to the soil surface or to foliage. Pesticides may be incorporated directly into the soil, usually at the top few millimeters to exert a biological effect. Pesticides may also enter the environment through accidental spill or waste disposal (Himel, Loates, and Bailey, 1990).

Environmental entry and transport processes start immediately after the pesticide has been applied. Irrigation or rainfall may modify the relative importance of the various components of these processes in determining the fate of the applied pesticide. Environmental sinks for pesticides include chemical, photochemical, and biological transformation, volatilization losses, erosion and runoff, leaching, and harvest removal and storage (Himel, Loates, and Bailey, 1990).

Figure 5.4 depicts the pesticide transport and transformation processes in the plant-soil-water environment.

The environmental pollution from pesticides is caused mainly by the physical processes of pesticide transfer. Several of these processes may be active

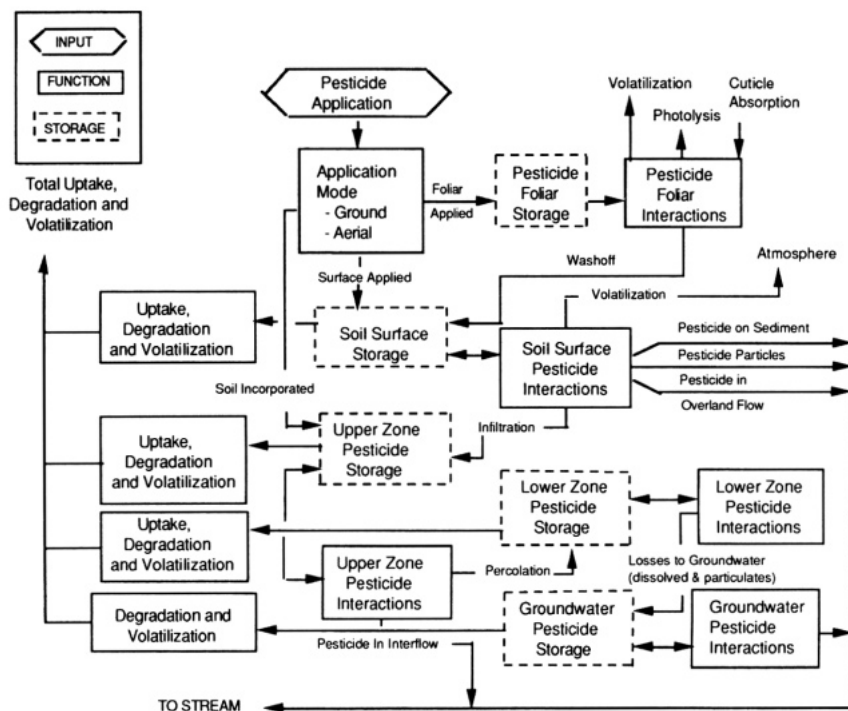


Figure 5.4. Pesticide Transport and Transformation in the Soil-Plant Environment and Vado se Zone

Source: After Donnigan and Crawford (1976).

simultaneously. Soil is contaminated by pesticide adsorption, surface water is contaminated by pesticides moved through runoff, groundwater quality is deteriorated by pesticides reaching the water table through ground leaching and deep percolation, and the atmosphere is polluted by the volatilization of pesticides. Through absorption by crops or aquatic animals, pesticide residues can get into human beings and animals that depend on them for food. Pesticide degradation processes decrease the severity of its concentrations in soil and water systems.

### 5.7.1. Surface Water Bodies

Runoff is the principal route for pesticides from ricefields to rivers, lakes, and marine ecosystems. Accumulation of pesticides in surface water bodies can have

far-reaching consequences for domestic water supply and aquatic organisms. Pesticide contamination of surface water bodies can be assessed by monitoring residue levels in aquatic food webs.

Herbicides used in ricefields have caused water quality problems in the Sacramento River, California, and restrictions have been imposed on their use to prevent or reduce contamination. The problem herbicides are thiobencarb, which gives a bitter taste to water, and molinate, which is toxic to fish. California regulations now require that, after the application of thiobencarb and molinate, water must be retained on the farm for fourteen and twelve days, respectively, to keep the concentration of thiobencarb in the river below 8 ppb and that of molinate below 4.5 ppb (Moody, 1990).

Aldrin applied to seed rice enters the aquatic ecosystem through ricefields and marshland drainage. Residue analysis of representative species of the aquatic biota indicated significant biological accumulation; rapid rise in the concentration of pesticides in living organisms resulted in a massive kill of aquatic organisms (Ginn and Fisher, 1974).

Herbicides applied in water reservoirs may have detrimental effects on rice. In southeastern Australia, acrolein, Dalapon, and TCA are applied in irrigation canals to control aquatic weeds. Bowmer et al. (1988) reported that seeded rice was damaged when exposed to acrolein-treated water. However, the rice was able to compensate for the early damage by tillering profusely and yields were increased by treatment with acrolein. To avoid detrimental effects of Dalapon or TCA on rice the time between treatment and water resupply to ricefields should be greater than six weeks (Bowmer, 1988).

We know very little about the problems of the kind discussed above about freshwater bodies of the third world countries, where pesticide use is increasing. A case study conducted in the Philippines is reported in Chapter 7.

### *5.7.2. Groundwater System*

Groundwater contamination by agricultural chemicals is a major environmental pollution issue. In recent years, a number of organic contaminants have been detected in groundwater samples. In the United States, seventeen different pesticides have been detected in groundwater in twenty-three different states; the concentrations typically ranged from trace amounts to several hundred parts per billion (Sun, 1986). However, no systematic studies have been conducted for detection of groundwater contamination in rice-growing areas of Asia, where multiple rice cropping with associated intensive pesticide use has been commonly practiced for many years. Groundwater contamination is probably higher in such areas than in more traditional one crop per year areas, particularly when

the water table is shallow and the aquifer is overlain by light-textured soils (Castañeda and Bhuiyan, 1990).

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# 6 ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF PESTICIDES IN PADDY RICE PRODUCTION

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## 6.1. Introduction

Pesticides, by design, are biocides; their utility lies in their ability to kill noxious or unwanted organisms, but they are rarely selective. Most pesticides act by interfering with fundamental biochemical and physiological processes that are common to a wide range of pests and nontarget organisms (Conway and Pretty, 1991). Assessing the hazards of pesticide use relies on a balance of evidence accumulated through different lines of inquiry. Thresholds are set and codes of safe practice established on the basis of biochemical studies, toxicity tests on a limited number of organisms, and field monitoring.

Pesticide use in rice production has been suspected of being a major contributor to environmental pollution. Farmers often spray hazardous insecticides like organophosphates and organochlorines up to five or six times in a cropping season when two applications may be sufficient. The usual practice of draining paddy water into irrigation canals may cause river and lake contamination. Residues carried by the water can be taken up by nontarget flora and fauna, leach into soil, and possibly contaminate groundwater or potable water. A greater problem lies in the bioaccumulation of pesticides in beneficial organisms like fish (see Chapter 8). Residues in food pose a hazard to consumers if the maximum residue limit (MRL) set by the FAO/WHO is exceeded.

However, the mere presence of a pesticide residue does not, in itself, represent a hazard; their significance depends on the concentration and their relative toxicity to environmental organisms.

Environmental safety studies conducted focus on two broad areas, environmental chemistry and ecology (Willis, 1988). Environmental chemistry studies involve physical and chemical degradation, mobility, metabolism, field dissipation, and accumulation. Physicochemical and metabolic studies identify residues formed. Mobility studies predict the movement of the pesticide and its residues outside the treated area, through leaching, volatility, adsorption, or dispersal by water. Field dissipation studies are conducted under actual use conditions to confirm data generated from laboratory studies. Accumulation studies assess the level of the pesticide residues in crops and nontarget organisms. Ecological studies include direct toxicity measurements under laboratory conditions on fish, birds, and other species of flora and fauna. Data from the two sets of studies are then evaluated to assess the potential impacts of pesticides on man, fish, wildlife, and other nontarget organisms.

The Pesticide Toxicology and Chemistry Laboratory of the National Crop Protection Center, University of the Philippines at Los Baños (NCPC-UPLB) assessed the fate of pesticides when applied in a ricefield ecosystem. Pesticides studied included carbofuran, carbosulfan, isoprocarb, BPMC, endosulfan, lindane, monocrotophos, and a formulated mixture of chlorpyrifos and BPMC (Tejada and Magallona, 1985; Celino, Gambalan, and Magallona, 1988; Varca and Magallona, 1987; Medina-Lucero, 1980; Tejada and Bajet, 1990).

This chapter reports the results of part of a multidisciplinary investigation to assess the environmental and health impacts of pesticides in ricefield ecosystems in the Laguna province of the Philippines. This chapter specifically addresses the on- and off-paddy effects of pesticides on rice plants, soil, paddy water, ricefield flora and fauna, groundwater, and well water.

## **6.2. General Methodology**

Extensive and intensive monitoring was conducted. The variables considered, time of sampling, and number of farms sampled in the two monitoring activities are summarized in Table 6.1.

### **6.2.1. Extensive Monitoring**

Thirty-two cooperator farms were selected in the rice-growing areas of Calauan, Calamba, Cabuyao, and Biñan, Laguna, Philippines, and were sampled for three

Table 6.1. Environmental and Biological Parameters and Sampling Information

| Parameters/Variables                 | Extensive Monitoring                                                                                                                                                 |                         | Intensive Monitoring                                                                     |                         |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|------------------------------------------------------------------------------------------|-------------------------|
|                                      | Time of Sampling                                                                                                                                                     | Number of Farms Sampled | Time of Sampling                                                                         | Number of Farms Sampled |
| On-paddy effects:                    |                                                                                                                                                                      |                         |                                                                                          |                         |
| Rice grains                          | At harvest (DS/WS 1989)                                                                                                                                              | 29                      | 0 (3 hrs), 1, 2, 3, 5, 7, 15, 30, and 45 days after last pesticide application (WS 1989) | 2                       |
| Rice plants                          | Before transplanting (WS 1989)                                                                                                                                       | 29                      |                                                                                          | 2                       |
| Paddy soil                           |                                                                                                                                                                      |                         |                                                                                          |                         |
| Paddy water                          |                                                                                                                                                                      |                         |                                                                                          |                         |
| Groundwater (soil solutions)         |                                                                                                                                                                      | 2                       |                                                                                          | 2                       |
| Vertebrates:                         | Once at prebooting stage (WS 1989; DS 1990)                                                                                                                          | 6                       |                                                                                          |                         |
| Fish                                 |                                                                                                                                                                      |                         |                                                                                          |                         |
| Frogs                                |                                                                                                                                                                      |                         |                                                                                          |                         |
| Chickens and ducks                   |                                                                                                                                                                      |                         |                                                                                          |                         |
| Invertebrates:                       | At prebooting and at 2 weeks before harvest (WS 1989); once (DS 1990)                                                                                                | 6                       |                                                                                          |                         |
| Snails                               |                                                                                                                                                                      |                         |                                                                                          |                         |
| Shrimps                              |                                                                                                                                                                      |                         |                                                                                          |                         |
| Herbivores, predators, and parasites |                                                                                                                                                                      |                         |                                                                                          |                         |
|                                      | At the vegetative, max tillering, and vegetative stages (DS/WS 1989; DS 1990)                                                                                        | 36                      |                                                                                          |                         |
| Aquatic organisms:                   | (WS 1989)                                                                                                                                                            | 32                      | 0 (3 hrs) up to 7 days after every pesticide application                                 | 3                       |
| Algae                                |                                                                                                                                                                      |                         |                                                                                          |                         |
| Zooplankton                          | Before harvest (DS 1989); Extensive: before planting; intensive: 0–7 days after every application (WS 1989); Every 2 weeks for the entire cropping season (DS 1990); | 30–36                   | 0 (3 hrs) up to 7 days after every pesticide application                                 | 3                       |
| Off-paddy effects:                   |                                                                                                                                                                      |                         |                                                                                          |                         |
| Well water                           | (DS/WS 1989)                                                                                                                                                         | 7                       |                                                                                          |                         |
| Surface water                        |                                                                                                                                                                      | 2                       |                                                                                          |                         |



cropping seasons: dry season (DS) 1989, wet season (WS) 1989, and DS 1990. Extensive data were collected at intervals each crop season for a wide range of environmental and biological parameters (Table 6.1). Pesticide residues were extensively monitored in rice plants, soil and soil solutions, algae, zooplankton, pests and beneficial arthropods, aquatic animal tissues, groundwater, and well water. The effect of pesticides on the population density of aquatic algae and zooplankton, and herbivores and beneficial arthropods were extensively monitored.

One kg rice grain samples were collected randomly at harvest of the 1989 DS and WS from twenty-nine farmers' fields in Calauan, Calamba, Cabuyao, and Biñan, Laguna. Half of each sample was analyzed as rough rice, and the other half as dehulled rice.

Composite soil samples were collected from field quadrants in twenty-nine farms to determine pesticide residue concentrations at the start of the 1989 WS before transplanting.

Insecticide movement in the groundwater was measured directly in two farmers' fields in Calamba and Calauan, Laguna. Soil solutions were collected at 25, 50, 125, and 175 cm below the soil surface, using ceramic porous cups fitted at the bottom end of a sampling tube (Figure 6.1). Since the soil was saturated, the hydraulic pressure allowed water in the soil to seep freely through the porous cup. At specific sampling dates, the accumulated solution was collected using small plastic tubes inserted down to the porous cups. Water samples were then sucked with a vacuum pump and drained to the collection jar. Forty soil solution samples and ten surface water samples were collected from the two farms. All samples were frozen prior to pesticide residue analysis.

Fish, frog, snail, and shrimp were collected in ricefields and adjacent irrigation canals of six farmers' fields in Biñan, Calauan, and Cabuyao. Fish, frogs, and shrimps were collected only once during the prebooting stage (about forty-five days after transplanting (DAT)) of the 1989 WS and 1990 DS since irrigation canals during the preharvest period were dry. Snails were sampled twice in the 1989 WS (prebooting stage and two weeks before harvest) and once (prebooting stage) in the 1990 DS. Chickens and ducks, known to forage in the ricefields, were collected when available. They were dewinged, debeaked, and gutted before freezing. Samples were weighed and frozen until analysis.

Zooplankton was identified and counted from 30-liter water samples collected from three preestablished sampling sites in each of the thirty-six farmers' plots in Laguna: nineteen in Calauan, eight in Calamba, seven in Cabuyao, and two in Biñan. The samples were taken from drainage outlets used by farmers to remove paddy water prior to harvesting. The samples were passed through a 80-um plankton net to obtain a 50 ml concentrate, which was preserved using 5 percent neutral formaldehyde. Water samples were collected from the same farmer plots in the 1989 DS and WS and in the 1990 DS. The 1989 DS samples

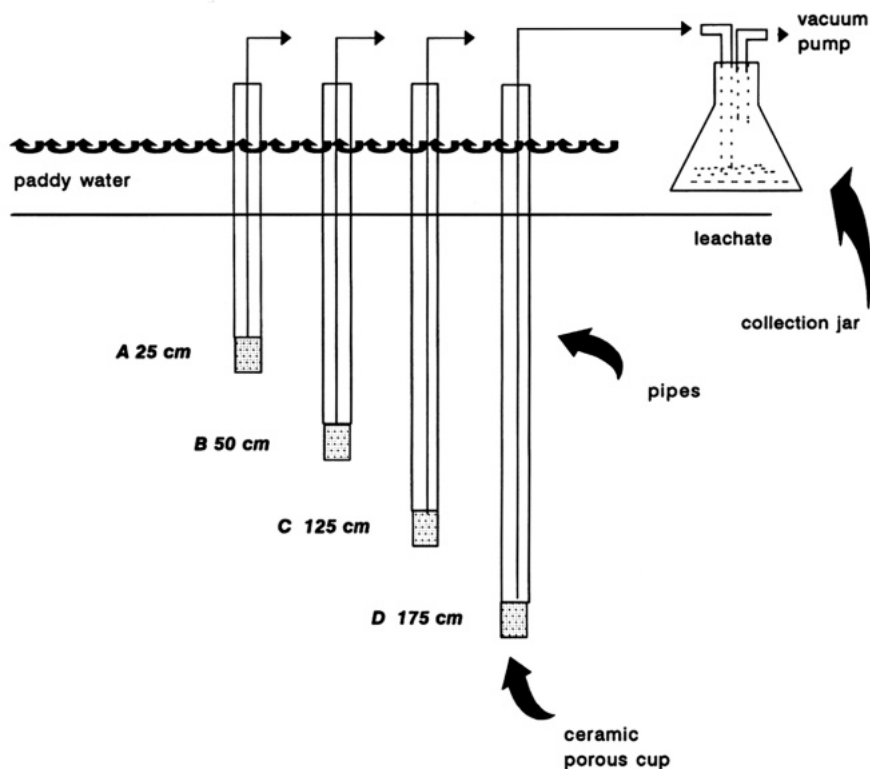


Figure 6.1. Method of Sampling Water at Different Depths

were taken from farm drainage outlets before harvest. All 1989 WS samples were collected before planting started. All samples for the 1990 DS were taken every two weeks for the entire cropping season and were replicated twice.

Algal population was determined from composite water samples collected randomly in a transect line cut across diagonally within the rice paddies to give a total of one-liter samples for each of the thirty-two farms in the 1989 WS and 1990 DS. Among the thirty-two farms, three were selected according to frequency of pesticide application, and were designated as (1) low, (2) semi-intensive, and (3) high-pesticide users. Samples were collected for seven consecutive days after every pesticide application starting from land preparation. Algae were concentrated at  $3,000 \times g$  for five minutes in a Kubota centrifuge model #KS-5200c, preserved in formalin-acetic acid alcohol (FAA) to give a final concentration of 3 percent in paddy water and refrigerated. Species were identified and counted

with the aid of a haemocytometer and a compound microscope (Martinez, Chakroff, and Pantastico, 1975).

Insects and arthropods were sampled in four 500 to 800 sq m areas in thirty-six Laguna farms at 15 to 20, 35 to 40, and 60 to 70 DAT in both the wet and dry seasons. These sampling periods corresponded with the vegetative, maximum tillering, and booting stages of the rice plant, respectively. Insects and arthropod populations were counted visually, weekly, on twenty randomly selected hills per field and collected using a standard 30-cm diameter sweep net at twenty-five sweeps per plot from 15 DAT until flowering. Insect samples were sorted, identified, and classified into herbivores, predators, and parasites.

Water samples (four liters) were collected from seven artesian wells in Calauan and Calamba (1989 DS, 1989 WS). The wells were located between 1 and 15 meters from the farmers' fields and were between 10 and 20 meters deep. The samples were analyzed for residues of commonly used insecticides: endosulfan, monocrotophos, chlorpyrifos, BPMC, and diazinon.

### 6.2.2. *Intensive Monitoring*

Prior to the intensive monitoring activity, high, semi-intensive, and low-pesticide-user farms were selected based on the results of an earlier rice production input-output survey.

The low-pesticide-user farm made its first pesticide applications 1 DAT and the last at 37 DAT (1989 WS) or 44 DAT (1990 DS) (Tables 6.2 and 6.3). The farm received 0.56 kg a/ha of pesticides in four applications in 1989 WS, and 0.67 kg ai/ha in three applications in 1990 DS. The high-pesticide-user farm made its first applications of pesticides 1 DAT and the last at 90 DAT (1989 WS) or 75 DAT (1990 DS). The high-pesticide-user farm received 1.29 kg ai/ha of pesticides in ten applications.

The semi-intensive pesticide user farm received 0.78 kg ai/ha of pesticides in the 1989 WS. No semi-intensive pesticide user farm was monitored in the 1990 DS.

Rice plant, soil, and floodwater samples were collected from each of the high- and low-pesticide-user farms at three hours, 1, 2, 3, 5, 7, 15, 30, and 45 days after the last pesticide application (1989 WS). Rice plant samples were separated into grains, leaves, and stems. All samples were analyzed for pesticide residues.

Floodwater samples for the estimation of zooplankton and algal populations were collected from three farmers' plots in Calauan identified as high, semi-intensive, and low-pesticide users (1989 WS). Samples were collected on seven consecutive days after each pesticide application.

Table 6.2. Pesticide Application Schedule of Rice Farmer Cooperators, Laguna, 1989 WS

| <i>Area</i>                      | <i>Rice</i> | <i>Date of Transplanting</i> | <i>Pesticide Applied</i> | Quantity per Farm | Date of Application |
|----------------------------------|-------------|------------------------------|--------------------------|-------------------|---------------------|
| <i>Low-pesticide-user farm:</i>  |             |                              |                          |                   |                     |
| 2.8 ha                           | C-4         | 7-11-89                      | Butachlor                | 1 liter           | 7-12-89             |
|                                  |             |                              | BPMC + chlorpyrifos      | 1/2 liter         | 8-10-89             |
|                                  | IR-10       | 7-23-89                      | Butachlor                | 1 liter           | 7-24-89             |
|                                  |             |                              | BPMC + chlorpyrifos      | 1/2 liter         | 8-31-89             |
| <i>High-pesticide-user farm:</i> |             |                              |                          |                   |                     |
| 4.7 ha                           | IR-70       | 6-8-89                       | Fentin sulfate           | 2 liters          | 6-8-89              |
|                                  | C-1         | 6-8-89                       | Niclosamide              | 2 liters          | 6-9-89              |
|                                  | Malagkit    | 6-8-89                       | Butachlor                | 4 liters          | 6-9-89              |
|                                  |             |                              | Chlorpyrifos             | 1 liter           |                     |
|                                  |             |                              |                          | 1 liter           | 6-28-89             |
|                                  |             |                              |                          | 2 liters          | 7-28-89             |
|                                  |             |                              |                          | 2 liters          | 8-23-89             |
|                                  |             |                              | Carbofuran               | 2 liters          | 8-24-89             |
|                                  |             |                              |                          | 1 bag             | 7-3-89              |
|                                  |             |                              | Isoprocab                | 2 bags            | 8-5-89              |
|                                  |             |                              |                          | 1 kg              | 8-5-89              |

### 6.2.3. Pesticide Residue Analysis

Rice grain, stalk, and leaf samples were prepared, and their pesticide residues analyzed by the procedure of Luke, Froberg, and Masumoto (1975).

Pesticide residues in the soil samples were estimated according to the procedure by Ambrus et al. (1981).

Pesticide residues in the paddy water and soil solution were estimated by a slightly modified version of the procedure described by the U.S. Environmental Protection Agency (1974). Well-water samples were estimated according to the procedure by Ohsawa et al. (1985).

Animal tissues were extracted with petroleum ether by Soxhlet. After evaporation, the fatty extracts were transferred to chromatographic columns and prepared for analysis. Residue concentrations were determined using gas chromatography (Mann, 1974).

Table 6.3. Pesticide Application Schedule of Rice Farmer Cooperators, Laguna, 1990 DS

| <i>Date of Transplanting</i>     | <i>Pesticide Applied</i> | <i>Quantity per Farm</i> | <i>Date of Application</i> |
|----------------------------------|--------------------------|--------------------------|----------------------------|
| <i>Low-pesticide-user farm:</i>  |                          |                          |                            |
| 12-20-89                         | Butachlor                | 1.0 liter                | 12-21-89                   |
|                                  | Monocrotophos            | 0.5 liter                | 1-9-90                     |
|                                  | Monocrotophos            | 0.5 liter                | 3-5-90                     |
| <i>High-pesticide-user farm:</i> |                          |                          |                            |
| 12-5-89                          | Fentin chloride          | 1.0 liter                | 12-6-89                    |
|                                  | Butachlor                | 2.0 liters               | 12-7-89                    |
|                                  | Monocrotophos            | 1.15 liters              | 12-22-89                   |
|                                  | Carbofuran               | 19.21 liters             | 1-9-90                     |
|                                  | 2,4-D                    | 0.29 liter               | 1-9-90                     |
|                                  | Cypermethrin             | 1.15 liters              | 2-3-90                     |
|                                  | Monocrotophos            | 0.57 liter               | 3-3-90                     |

#### 6.2.4. Controlled Field Experiment

A controlled field experiment that simulated a low-pesticide-user farm was conducted at the UPLB Central Experiment Station to confirm observations made in the intensively monitored farmers' field. Three 20 m × 25 m rice-fish paddies (Figure 6.2) were treated separately with the recommended application rates of 0.15 kg ai/ha monocrotophos, 0.30 kg ai/ha chlorpyrifos, and 0.35 kg ai/ha endosulfan at 15 and 40 DAT. Pesticide selection was based on the results of the groundwater pesticide movement study and the residues found in ducks. Samples of floodwater and soil were analyzed at zero to thirty days after last spraying of the pesticide. A trench was constructed on each side of the paddy to serve as refuge and collection point for fish during and immediately after pesticide application. Rice grains and fish samples were collected at harvest.

Pesticide concentrations in the air were measured by installing pieces of fine nylon mesh treated with ethylene glycol on sticks at different distances from the treated area. The traps were installed three and twenty-four hours after pesticides were applied and exposed for twenty-four hours.

Residue concentrations were measured by the procedures described in Section 6.2.3.

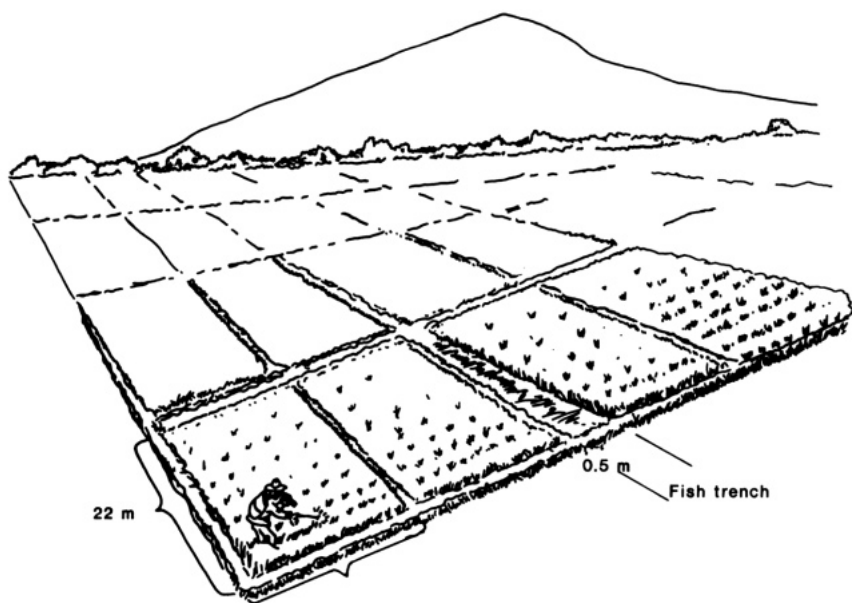


Figure 6.2. Schematic Diagram of Rice-Fish Culture at the Central Experiment Station, University of the Philippines at Los Baños, Los Baños, Laguna, Philippines

#### 6.2.5. *Rapid Field Method for the Detection of Organophosphate Insecticides*

Corollary to the controlled experiment, a rapid field method for organophosphate (OP) detection was tested. The method, developed at the NCPC Pesticide Toxicology and Chemistry Laboratory, was based on the procedure of Berck, Iwata, and Gunther (1978) and modified for Philippine field conditions. The primary objective of the study was to simplify the conventional method of pesticide residue analysis and thereby develop the method into a field kit. The technique was used to monitor pesticide contamination of paddy water drained into the irrigation canals, rice leaves, and the atmosphere. The results were used to determine the safe reentry period in the ricefield.

**6.2.5.1. The Rapid Field Kit.** Strips of Whatman #1 filter paper were treated with a chromogenic solution (Solution I) and air dried. Shelf life of the pretreated paper and the detection limit for each organophosphate pesticide were determined. Different formulations of pesticides at 1 ppm were spotted on the filter paper strips, which were placed between glass slides and heated over an alcohol

lamp for 30 seconds. After the addition of one drop of an alkaline solution (Solution II), a color change ranging from light to dark blue indicated the presence of residues. The pesticide concentration can be estimated by comparison with a color chart ranging from 0.1 to 10  $\mu\text{g}$ . The amount of residues remaining in the food or the environment can be calculated using the formula below:

$$C_{(\mu\text{g/g})} = \frac{(\mu\text{g}) \text{ from visual comparison/vol. spotted} \times \text{total volume of extract}}{\text{total weight of sample extracted (g)}}$$

**6.2.5.2. Field Treatment and Sampling.** Two 500 sq cm paddy fields were treated with monocrotophos and chlorpyrifos at the recommended rate of 0.3 kg ai/ha and 0.5 kg ai/ha, respectively. Paddy water samples were collected three hours after application of the pesticide. A 20-ml sample was taken and extracted with 1 ml methylene chloride by shaking in a vial. A drop of the methylene chloride extract was spotted on the filter paper strip, and followed the procedure described above in the rapid field kit.

Monitoring of pesticide residues in air trapped in nylon mesh cloth, rice leaves, and stored rice grains were also done using the rapid field kit.

### 6.3. Results of the Extensive Monitoring Survey

#### 6.3.1. On-Paddy Pesticide Effects

**6.3.1.1. Rice Grains at Harvest.** Random sampling of dehusked and rough rice from the 1989 DS and WS harvests in seventeen farms showed no detectable levels of chlorpyrifos, BPMC, methyl parathion, diazinon, monocrotophos, and endosulfan. This could be explained by the thirty- to forty-day interval between last pesticide application and harvest that allowed adequate time for pesticide degradation.

Previous laboratory studies showed that five days after application, residues of methyl parathion, monocrotophos, tetrachlorvinphos, and triazophos were no longer detected on treated vegetables (Tejada, Varca, and Magallona, 1977). BPMC on rice was lost rapidly and detected on rough and milled rice at 0.2 and 0.03 mg/kg, respectively, five days after application (Varca and Magallona, 1987). The rapid loss of these pesticides can be attributed to the compounds' low vapor pressure and to exposure to solar radiation. Photodecomposition studies under artificial sunlamp showed a rapid degradation of organophosphorous pesticides (Calumpang, Tejada, and Magallona, 1985).

Monitoring studies conducted in eighteen National Grain Authority (NGA) warehouses in the Philippines (NCPC, 1981) showed that postharvest treatment

with pesticides resulted in considerable amounts of residues in stored grains. The residues were however within the limit set by the FAO/WHO for grains (7.0 mg/kg).

**6.3.1.2. Soil.** Soil samples collected in the 1989 WS did not contain detectable residues of BPMC, chlorpyrifos, monocrotophos, endosulfan, and diazinon. Similarly, there was no detectable residues of previously applied pesticides in soil collected before transplanting in the 1990 DS. This indicated that pesticide residue did not accumulate in the soil. Similar results were obtained after repeated applications of carbosulfan (Tejada and Magallona, 1985), endosulfan and lindane in lowland ricefields (Medina-Lucero, 1980).

**6.3.1.3. Movement of Pesticides in Groundwater.** The amount and rate of pesticide residue movement through the soil profile and into the groundwater are governed by the interaction of several processes (Figure 6.3). Downward flux of pesticide residues is enhanced by mass flow and diffusion. Concentrations of dissolved residues decrease with time and soil depth because of biological and chemical decomposition and sorption by the soil. Surface runoff, seepage, volatilization, and plant uptake also contribute to the decrease (or increase) of residue leaching to the groundwater (see Chapter 5).

The concentration of monocrotophos residues (CMR) detected in the flood-water and soil solutions over time and at different soil depths following pesticide applications in Calamba during 1989 DS are presented in Table 6.4. Foliar application of 0.30 kg ai/ha on three-week-old transplanted rice resulted in a high CMR of 32 ug/L in the paddy water six hours after spraying, but it was not detectable two weeks later. The rapid decline in CMR in the paddy water can be attributed to microbial and photochemical degradation, sorption, volatilization, surface drainage, and leaching.

Significant amounts of residues leached into the soil to depths of 25 to 175 cm during the first week after spraying (Table 6.4). Monocrotophos residues followed the classical behavior of solute movement in the soil. That is, CMR reached a peak at a particular soil depth and then declined with time. This is usually observed for compounds miscible in soil water that move by mass flow and diffusion but are degraded, decayed, or absorbed in the soil. At a soil depth of 25 cm, peak CMR (8.86 ug/L) was observed on the day of application and then declined rapidly, reaching nondetectable levels in the second week.

At the 50-, 125- and 175-cm soil depths, peak CMR (8.34, 4.99 and 0.66 ug/L, respectively) were observed in the second week after spraying. CMR in the deeper soil did not decrease to the minimum detectable limit (Table 6.4), indicating that dissipation rates decreased with soil depth. While monocrotophos was not detectable at the 25-cm soil depth after only two weeks, it took two



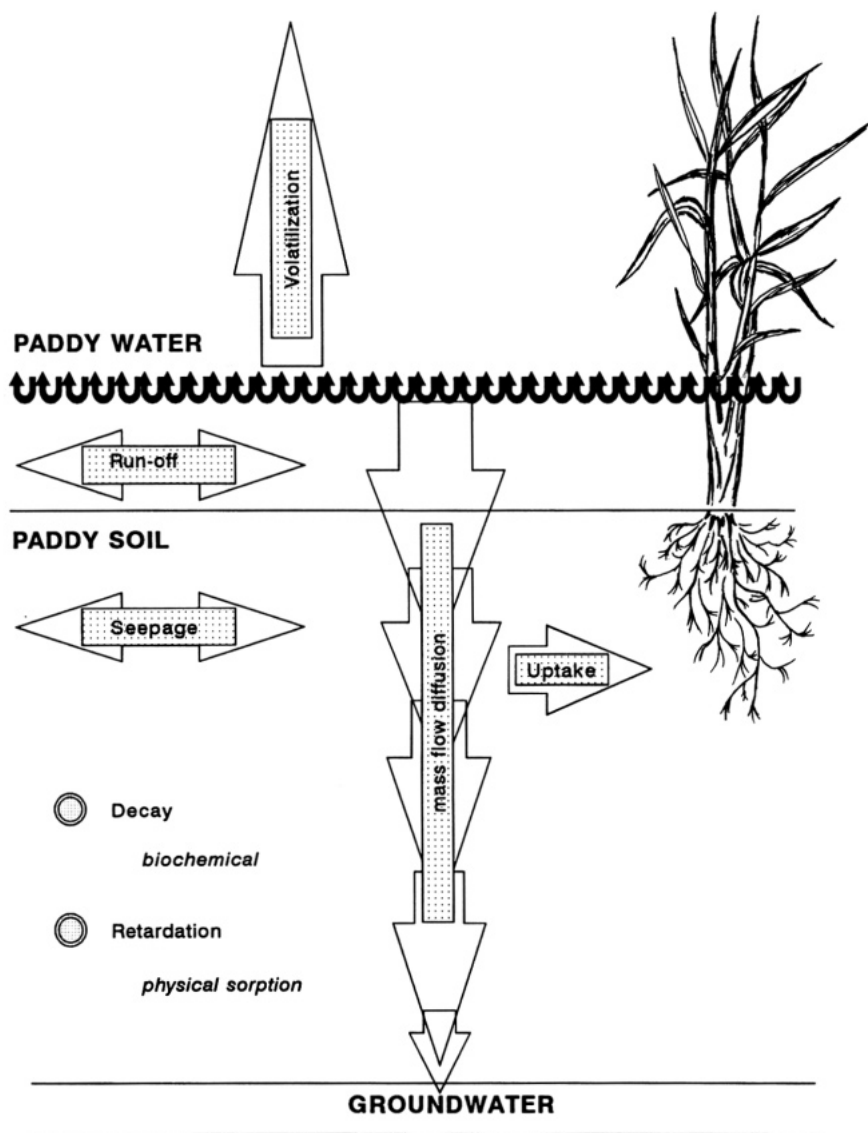


Figure 6.3. Conceptual Representation of Pesticide Residue Movement in a Lowland Rice Production System

Table 6.4. Monocrotophos Residues (ug/L) Detected at Different Soil Depths Following Three Applications in Rice, Calamba, Laguna, 1989 DS <sup>a</sup>

| Soil Depth (cm) | January 9          | January 16  | January 23       | January 30  | February 6  | February 13 |
|-----------------|--------------------|-------------|------------------|-------------|-------------|-------------|
|                 | 6 HAS <sup>b</sup> | 7 DAS       | 14 DAS           | 21 DAS      | 28 DAS      | 35 DAS      |
| 0               | 31.68 ± 3.79       | 1.97 ± 0.04 | NDR <sup>c</sup> | d           | NDR         | NDR         |
| 25              | 8.86 ± 0.40        | 4.82 ± 0.43 | NDR              | NDR         | NDR         | NDR         |
| 50              | 3.02 ± 0.48        | 5.70 ± 0.88 | 8.34 ± 1.45      | 0.78 ± 0.06 | NDR         | NDR         |
| 125             | 1.06 ± 0.15        | 2.86 ± 0.38 | 4.99 ± 1.04      | 0.38 ± 0.04 | 1.31 ± 0.14 | 0.29 ± 0.06 |
| 175             | NDR                | 0.54 ± 0.04 | 0.66 ± 0.04      | 0.28 ± 0.01 | 0.24 ± 0.08 | 0.40 ± 0.02 |

Note: Minimum detectable limit (MDL) at 5:1 signal to noise ratio : 0.03 ng/ml of sample.

a. First spraying, 12–27–89; 2nd spraying, 1–9–90; 3rd spraying, 1–27–90 (application rate = 0.30 kg a.i./ha/spraying).

b. Hours after the second spraying.

c. NDR-no-detectable residue.

d. No surface water.

Table 6.5. Endosulfan Residues (ug/L) at Different Soil Depths Following Two Applications in Rice, Calauan, Laguna, 1990 DS

| Soil Depth<br>(cm)                                                                                   | January 26<br>6 DAS <sup>a</sup> | February 20<br>31 DAS | March 20<br>59 DAS | April 3<br>73 DAS |
|------------------------------------------------------------------------------------------------------|----------------------------------|-----------------------|--------------------|-------------------|
| <i>Endosulfan applied at the rate of 0.35 kg a.i./ha<br/>on January 20, 1990 and March 14, 1990.</i> |                                  |                       |                    |                   |
| 0                                                                                                    | 0.037 ± 0.000                    | Trace                 | 0.038 ± 0.006      | -                 |
| 25                                                                                                   | 2.467 ± 0.057                    | Trace                 | 0.483 ± 0.089      | -                 |
| 50                                                                                                   | 0.390 ± 0.003                    | 0.060 ± 0.005         | 0.262 ± 0.049      | NDR <sup>b</sup>  |
| 125                                                                                                  | 0.104 ± 0.001                    | 0.035 ± 0.000         | 0.122 ± 0.005      | 0.153 ± 0.000     |
| 175                                                                                                  | Trace                            | 0.053 ± 0.004         | 0.044 ± 0.006      | 0.009 ± 0.000     |

Note: Minimum detectable limit (MDL) at 5:1 signal to noise ratio: alpha = 0.009 ng/ml sample; beta = 0.011 ng/ml sample.

a. Days after the first spraying.

b. NDR no detectable residue.

more weeks to degrade to nondetectable levels at the 50-cm depth. Monocrotophos residues persisted in the 125- to 175-cm soil depths for up to 73 days. This was possibly due to the absence of microbial activity at these depths.

Concentrations of endosulfan residues (CER) in the soil solutions collected at different soil depths and times after applying pesticides in Calauan during 1990 DS are presented in Table 6.5. Endosulfan residue levels were generally lower than those of monocrotophos; however, their movement and accumulation were similar. Significant amounts of endosulfan residues leached through the soil during the first week. Four weeks after spraying, only trace amounts of endosulfan residues were detected in the paddy water and in the surface (25-cm) soil solution. Half-life of endosulfan in the paddy water was about ten days.

CER in the soil peaked within six days after spraying at the 0 to 50-cm depth, and after one month at the 175-cm depth. It took CER seventy-three days after the first spraying to peak at the 125-cm soil depth. Similar to CMR, small amounts of endosulfan residues persisted in the 125- and 175-cm soil depth for more than two months after application. Results from the analysis of monocrotophos and endosulfan residues in paddy and groundwater indicate possible contamination of the potable water sources (see section on well waters).

**6.3.1.4. Pesticide Effects on Zooplankton and Algae.** During the 1989 DS, twenty (66.6 percent) out of the thirty sampled ricefields yielded zooplankton; in the 1989 WS, twenty-five (83 percent) out of the thirty-six sampled ricefields

yielded zooplankton. Copepods were dominant in the 1989 DS (44 percent), followed by cladocerans (40 percent) and ostracods (15 percent). In the 1989 WS, ostracods were dominant (42 percent), followed by cladocerans (38 percent) and copepods (20 percent).

Results indicate that zooplankton colonization of ricefields is dependent on season and agricultural practices.

Populations fluctuate during the crop season in response to flooding, plowing, field drainage, and pest control. Populations are typically absent prior to flooding and at harvest when the fields are normally dry. Zooplankton populations survive such unfavorable conditions as desiccation resistant eggs in the soil. After flooding and when temperatures are favorable, the eggs hatch and zooplanktons recolonize the floodwater.

The canonical correspondence analysis (CCA) ordinations of the farmers' plots including their respective environmental parameters are presented in Figure 6.4.

The arrows in all the ordination plots represent the environmental factors. The direction of the environmental factor vectors indicate their relationship with either the farmer's plots or the zooplankton groupings. The lengths of the vectors indicate the strength of their relationships.

The ordination of the farmer's plots with the environmental factors in Figure 6.4 shows that exposure to insecticides was the most important factor influencing zooplankton abundance in the course of the entire cropping season followed by herbicides. The direction of the insecticide vector points to the ricefield, which have been described to have dominant cladocera group that is highly affected by the application of insecticides. Among the insecticides used, carbamates appear to exert the most influence, followed by organochlorines, organophosphates, and unclassified insecticides in decreasing order. An Eigenvalue of 0.44169 means that 44 percent of the variability in zooplankton abundance can be explained by the effect of pesticide use on the farmers' plots.

In terms of zooplankton groupings, majority of the farmers' plots appear to be largely determined by ostracod and cladocera populations, with ostracods appearing to be a dominant feature of most farms. Among the three zooplankton groupings, ostracods seem to be the least affected by pesticide use, followed by copepods. Cladocerans, on the other hand, appear to be the most sensitive to pesticide applications.

An extensive survey of phytoplankter in the rice farms of Cabuyao, Calamba, and Calauan, Laguna during the 1989 WS showed varying dominant groups of algae. Green algae were predominant in Cabuyao, whereas the ricefields in Calamba and Calauan had relatively more diatoms. Such differences in species dominance may be attributed to several interacting biotic and abiotic parameters.

Algal population peaked before maximum tillering (35 to 40 DAT), while the

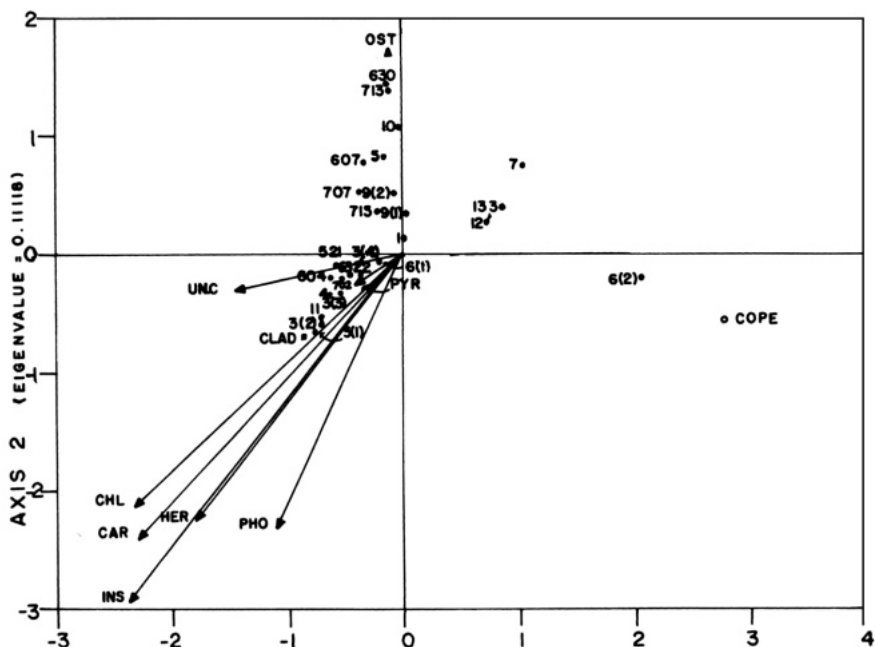


Figure 6.4. Canonical correspondence analysis (CCA) ordinations of farmers' plots

Note: The solid points are the data points (from each farmer's plot) yielding a principal coordinate analysis (PCA). Each point is labeled with a number denoting the codes assigned for each farmer's plot.

Legend: *Organism*

Type of pesticide

OST = ostracods

PYR = pyrethroids

COPE = copepods

PHO=organophosphates

CLAD = cladocerans

CHL = organochlorines

HER = herbivores

CAR = carbamates

INS = insects

UNC=unclassified

population was relatively low just after transplanting and before harvest. This direct relationship between algal population and density of rice plant tillers seem to be inversely related to the amount of pesticides available in the floodwater. It seems that spraying of the pesticides made the chemical available to the floodwater and affected the microflora in that habitat at land preparation and near harvest time. On the other hand, at maximum tillering, the rice tillers filtered the pesticide chemicals and hence did not affect the microflora of the floodwater.

**6.3.1.5. Pesticide Effect on the Densities of Herbivores, Predators, and Parasites.** One deleterious characteristic of agricultural pesticides is that they kill not only target organisms but also predatory species that may have kept pest species at reasonably low levels. It is for this reason that herbivores, predators, and parasites were studied in this investigation.

Differences in herbivore, predators, and parasites densities were observed in samples collected from ricefields with different pest control practices in both wet and dry seasons. Pest densities were generally very low at fifteen days after transplanting in both the dry and wet seasons, but 75 percent of the farmers still applied insecticides. This practice was less effective at preventing pest buildup at rice maturity than an application during the tillering stage when pest populations were relatively high. Pesticide applications at inappropriate times are not only ineffective and uneconomic; they contribute to unnecessary environmental pollution.

### 6.3.2. Off-Paddy Effects

**6.3.2.1. Residues in Animal Tissues.** Snail populations were relatively low in the 1989 WS, possibly due to snail control practices widespread among the farmers. Snail tissue samples collected had no detectable residue of BPMC, chlorpyrifos, and isoprocarb. This may have been due to the average ten-day interval between the second pesticide application and sampling, which allowed degradation of the toxicants in the environment. Chlorpyrifos + BPMC degrade rapidly in the ricefields with half-life values of only 0.9 day for BPMC and 0.6 day for chlorpyrifos (Zulkifli, Tejada, and Magallona, 1983).

Samples of Nile tilapia (*Oreochromis niloticus*), "hito" (*Chanas barrachus*), mudfish (*Ophicephalus striatus*), and freshwater shrimp (*Macrobrachium* sp.) collected during the 1989 WS showed no detectable residues of monocrotophos, BPMC + chlorpyrifos, chlorpyrifos, and methyl parathion. This again can be attributed to the degradation and solubility potentials of the compounds in the ricefields.

All extracts of these same animal tissues however exhibited possible presence of isoprocarb residues with peaks ranging from 0.51 to 0.56 mg/kg. Isoprocarb is not very soluble in water and could easily be absorbed through the gills, facilitated by the countercurrent flow mechanism, before it was degraded. Bajet and Magallona (1982) reported that isoprocarb had a 38.5-day half-life in flooded soils, and was detectable in fish tissues as early as one day after exposure.

Frogs collected in the same canal exhibited a pesticide degradation pattern similar to that found in fish and shrimps. The peaks, however, correspond to the average retention time of isoprocarb and BPMC at 0.55 and 0.64 minutes,

Table 6.6. Pesticide Residues Detected in Some Aquatic Organisms and Animals Found Within Rice Farms During the Prebooting Stage of Rice, Laguna, 1990 DS

|      | <i>Species</i>                              | <i>Insecticide Used</i>     | <i>Residue Level<br/>(mg/kg)</i> |
|------|---------------------------------------------|-----------------------------|----------------------------------|
| I.   | Snails                                      | Monocrotophos               | trace                            |
|      |                                             | Chlorpyrifos + BPMC         | NDR                              |
|      |                                             | Monocrotophos + fenvalerate | trace                            |
|      |                                             | Endosulfan                  | NDR                              |
|      |                                             | Chlorpyrifos                | NDR                              |
| II.  | Fish                                        |                             |                                  |
|      | Tilapia<br>( <i>Oreochromis niloticus</i> ) | Chlorpyrifos                | NDR                              |
|      |                                             | Monocrotophos               | NDR                              |
|      |                                             | Decamethrin                 | NDR                              |
|      |                                             | Chlorpyrifos + BPMC         | NDR                              |
|      | “Hito”<br>( <i>Chanas batrachus</i> )       | Methyl parathion            | NDR                              |
|      |                                             | Carbofuran                  | NDR                              |
|      |                                             | MIPC                        | NDR                              |
|      | Shrimps<br>( <i>Macrobrachium</i> sp.)      |                             |                                  |
| III. | Duck                                        |                             |                                  |
|      | Heart                                       | Chlorpyrifos                | 0.020                            |
|      | Muscle                                      |                             | 0.027                            |
| IV.  | Mudfish<br>( <i>Ophicephalus striatus</i> ) | Chlorpyrifos                | NDR                              |
| VI.  | Gurami                                      | Chlorpyrifos                | NDR                              |
| VII. | Chicken                                     |                             |                                  |
|      | Brain                                       | Chlorpyrifos                | 0.140                            |
|      | Heart                                       |                             | 0.030                            |
|      | Muscles                                     |                             | 0.025                            |

respectively. Extracted organs showed peaks as follows: kidney, 0.57; brains, 0.55 and 0.69; muscle, 0.58; and heart, 0.66. The data implies that isoprocarb residues may concentrate more in the brain tissues while BPMC residues, in muscle tissues, kidney, and heart. Bajet and Magallona (1982) reported that isoprocarb was concentrated more in the fish head.

Chicken samples from Biñan and Calauan exhibited no detectable residue of the parent compounds of pesticides applied by the farmers.

Residues of most of the insecticides applied by the farmers (except chlorpyrifos) were not detected in the 1990 DS animal tissue samples from Biñan and Calauan (Table 6.6). These compounds included monocrotophos,

butachlor, methyl parathion, ethofenprox, oxadiazon, and fentin chloride. This can be explained by the ten- to twenty-one-day interval between the last pesticide application and sampling, allowing significant degradation of the parent compounds. In 1990, Tejada and Bajet reported that monocrotophos may degrade within five days in rice paddy water, with a half-life of 0.9 day.

Suspected residues of chlorpyrifos were detected in frog, duck, and chicken tissue samples collected from irrigation canals in Biñan and Calauan (Table 6.6). The residues appeared to be more concentrated in the brain (0.1 mg/kg) than in any other organ (0.02–0.03 mg/kg). The origin of the chlorpyrifos is unknown because it was not applied by the farmer cooperators. Perhaps adjacent irrigation canals were contaminated from neighboring farms or the animals also foraged in fields where it was applied. Compared to other organophosphates, chlorpyrifos is relatively stable in soil and water, so it could persist long enough to be imported into the system.

The chlorpyrifos residue levels found in the samples of duck and chicken were all within the acceptable daily intake (ADI) <sup>1</sup> level set by the FAO/WHO. Daily intake of residues is calculated by using the following equation:

$$\text{Daily intake (DI)} = \frac{R \times F}{P}$$

where  $R$  = residue level in fish,  $F$  = daily fish consumption, and  $P$  = average weight of a person.

Assuming that an average person weighing 50 kg consumes 100 g of fish per day containing 0.027 mg chlorpyrifos residues per kg of fish, then  $DI = (0.027 \text{ mg/kg} \times 0.1 \text{ kg})/60 \text{ kg body weight} = 0.0004 \text{ mg/kg body weight}$ . This is below the FAO/WHO ADI for chlorpyrifos of 0.01 mg/kg.

**6.3.2.2. Contamination of Well Waters.** Well water sampled during the 1989 DS did not contain any detectable residue of endosulfan, monocrotophos, chlorpyrifos, BPMC, or diazinon. Traces of monocrotophos, endosulfan, and chlorpyrifos were detected in some wells during the 1989 WS (Table 6.7).

Wells sampled from farms in Calauan and Calamba contained endosulfan residues ranging from 0.002 to 0.03 ug/L and monocrotophos, from 0.1 to 1.84 ug/L. Chlorpyrifos was detected at 0.032 ug/L in only one Calauan farm. The artesian well that tested positive with 1.80 ug/L monocrotophos, 0.031 ug/L chlorpyrifos, and 0.030 ug/L endosulfan was located nearest to the ricefield and was only 30 feet deep. In Calamba, monocrotophos was detected in the two wells sampled, which were located one to two meters from ricefields receiving frequent application of the compound. These results indicate that groundwater has been contaminated with residues of monocrotophos, endosulfan, and chlorpyrifos in some rice-growing areas where pesticides have been applied intensively.



Table 6.7. Residues (ug/L) of Commonly Used Insecticides in Well Water Near Rice Paddies, Calauan and Calamba, Laguna, 1989 WS

| <i>Artesian Well</i> | <i>Endosulfan</i> | <i>Monocrotophos</i> | <i>Chlorpyrifos</i> | <i>Diazinon</i> | <i>BPMC</i> |
|----------------------|-------------------|----------------------|---------------------|-----------------|-------------|
| Calauan:             |                   |                      |                     |                 |             |
| Well 1               | 0.030 ± 0.001     | 1.84 ± 0.064         | 0.032 ± 0.006       | NDR             | NDR         |
| Well 2               | NDR <sup>a</sup>  | NDR                  | NDR                 | NDR             | NDR         |
| Well 3               | 0.011 ± 0.003     | NDR                  | NDR                 | NDR             | NDR         |
| Well 4               | 0.011 ± 0.001     | NDR                  | NDR                 | NDR             | NDR         |
| Well 5               | 0.002 ± 0.000     | NDR                  | NDR                 | NDR             | NDR         |
| Calamba:             |                   |                      |                     |                 |             |
| Well 1               | NDR               | 0.22 ± 0.027         | NDR                 | NDR             | NDR         |
| Well 2               | NDR               | 0.10 ± 0.009         | NDR                 | NDR             | NDR         |

Note: MDL = minimum detectable (ug/L) ADI = acceptable daily intake

|                  |       |               |       |
|------------------|-------|---------------|-------|
| Alpha-endosulfan | 0.009 | Endosulfan    | 0.008 |
| Beta-endosulfan  | 0.011 | Monocrotophos | 0.003 |
| Monocrotophos    | 0.03  | Chlorpyrifos  | 0.01  |
| Chlorpyrifos     | 0.02  | BPMC          | 0.002 |
| Diazinon         | 0.007 |               |       |
| BPMC             | 0.093 |               |       |

a. NDR = no detectable residue.

As these wells are sources of drinking water for a number of families, pesticide residue levels detected were also correlated to the acceptable daily intake (ADI) values set by the FAO/WHO. Calculation was based on a daily water intake of eight glasses (at 8 oz/glass) for an average 50-kg person. The highest residue levels detected for endosulfan, chlorpyrifos, and monocrotophos gave a daily intake lower than the recommended level of 0.006 mg/kg body weight (FAO/WHO, 1989), 0.01 mg/kg body weight (FAO/WHO, 1985), and 0.0006 mg/kg body weight (IPCS, 1990), respectively. This, however, does not take into account other possible sources of insecticide residues like vegetables, meat sources, and other foods.

## 6.4. Intensive Monitoring Survey of Pesticide Residues

### 6.4.1. On-Paddy Effects

**6.4.1.1. Chlorpyrifos Degradation in Farmers' Fields.** Chlorpyrifos residues were only detectable in the floodwater of the high-pesticide-user farm for three

Table 6.8. Chlorpyrifos Residues Detected in Some Components of the Rice Paddy Ecosystem in Farmer-Cooperators' Fields, Laguna, 1989 WS

| Days After Application           | Residues (mg/kg) |                |               |               |
|----------------------------------|------------------|----------------|---------------|---------------|
|                                  | Water            | Rice Stalks    | Rice Leaves   | Soil          |
| <i>Low-pesticide-user farm:</i>  |                  |                |               |               |
| 0(3 hrs)                         | < .001           | 0.09 ± 0.020   | 0.24 ± 0.050  | 0.040 ± 0.010 |
| 1                                | < .001           | 0.05 ± 0.001   | 0.39 ± 0.070  | 0.150 ± 0.030 |
| 2                                | < .001           | 0.04 ± 0.010   | 0.21 ± 0.005  | 0.040 ± 0.020 |
| 3                                | < .001           | 0.03 ± 0.004   | 0.13 ± 0.020  | 0.002 ± 0.005 |
| 5                                | < .001           | 0.03 ± 0.005   | 0.07 ± 0.001  |               |
| 7                                | < .001           | 0.05 ± 0.01    |               |               |
| <i>High-pesticide-user farm:</i> |                  |                |               |               |
| 0(3 hrs)                         |                  | 0.003 ± 0.001  | 0.09 ± 0.01   | 0.25 ± 0.04   |
| 1                                | 0.001 f 0.004    | 0.006 ± 0.0001 | 0.12 ± 0.005  | 0.23 ± 0.01   |
| 2                                | 0.001 f 0.007    | 0.009 ± 0.0003 | 0.10 ± 0.02   | 0.21 ± 0.02   |
| 3                                | 0.001 f 0.005    | 0.01 ± 0.005   | 0.07 ± 0.03   | 0.11 ± 0.07   |
| 5                                | < 0.001          | 0.002 ± 0.0002 | 0.01 ± 0.003  | 0.06 ± 0.01   |
| 7                                | < 0.001          | < 0.001        | —             | 0.08 ± 0.01   |
| 15                               | < 0.001          | < 0.001        | 0.003 ± 0.005 | 0.05 ± 0.02   |

Note: Minimum detection limit (MDL) = 0.001 mg/kg.

days after application; half-life was 1.87 days (Table 6.8). Residues in the low-pesticide-user farm were below the minimum detectable limit (0.001 mg/L) three hours after application. These findings are broadly in agreement with Zulkifli, Tejada, and Magallona (1983) and Smith, Betty, Watson, and Sebold (1966).

Chlorpyrifos residues were detected in the rice stems up to five days after the last pesticide application in the high- and low-pesticide-user farms (Table 6.8). Residues in the high-pesticide-user farm gradually increased until the fifth day, while those in the low-pesticide-user farm reached a maximum on the last day of application and then gradually decreased. These peak periods coincided with the highest chlorpyrifos residue concentration in floodwater. This could be the period of maximum absorption of chemicals by the rice plants from the flood water by capillary action.

Chlorpyrifos residues on rice leaves were detectable up to the fifteenth day in the high-pesticide-user farm and up to the seventh day in the low-pesticide-user farm. Maximum concentration of chlorpyrifos residues was recorded one

day after the last application in both farms. Among all components analyzed in the low-pesticide-user farm, rice leaves had the highest level of chlorpyrifos residues detected.

As in the extensive monitoring survey, dehusked and rough rice grains from the 1989 WS harvest did not contain detectable pesticide residue. Therefore, the usual practice of harvesting rice forty days after last application may be considered safe from the consumer's standpoint.

Analysis of soil from a high-pesticide-user farm showed residue levels higher than those in the rice plant (Table 6.8). At 0 day after application, 0.25 mg/kg of chlorpyrifos residue was detected in the soil while only 0.09 mg/kg was detected on rice leaves. Rainfall may have washed out chlorpyrifos residues from the leaves and deposited them on the soil. Rainfall is known to reduce pesticide residues on leaves by as much as 90 percent (Tejada and Magallona, 1985). Soil retains pesticide residues longer than any other ricefield ecosystem component, primarily due to adsorption and bound residue formation, thus making the soil the ultimate sink of pesticide deposition.

The level of chlorpyrifos residues in the soil from the high-pesticide-user farm was highest at application, and gradually declined in the next days. The same trend was observed in the soil sampled in the low-pesticide-user farm.

**6.4.1.2. Monocrotophos Degradation in Farmers' Fields.** Monocrotophos residues were not detectable in either soil or floodwater of the high- and low-pesticide-user farms (Table 6.9), even on the day of application. Therefore, monocrotophos residues should not accumulate under ricefield conditions in these components of the ecosystem.

Monocrotophos residues were detected on rice leaves up to three days after the last spray application in the low pesticide user farm and up to five days in the high-pesticide-user farm (Table 6.9). The residues did not exceed the maximum residue limit (MRL)<sup>2</sup> of 0.05 mg/kg set by FAO/WHO for some agricultural commodities. A fourteen-day preharvest interval (PHI) is recommended by FAO/WHO but, under tropical conditions, a seven-day PHI may be considered acceptable for monocrotophos. Residue levels in rice stems and leaves were similar in the high- and low-pesticide-user farms.

Results of this study complement those of Tejada and Magallona (1985), Varca and Magallona (1987), Celino, Gambalan, and Magallona (1988), and Tejada and Bajet (1990).

**6.4.1.3. Controlled Field Experiment.** The degradation pattern of monocrotophos, chlorpyrifos, and endosulfan was consistent with observations made in farmers' fields. Monocrotophos residues, however, were detected in floodwater up to three days after spray application (Table 6.10). This could again be due

Table 6.9. Monocrotophos Residues Detected in Some Components of the Rice Paddy Ecosystem in Farmer-Cooperators' Fields, Laguna, 1990 DS

| <i>Days After<br/>Application</i> | <i>Residues (mg/kg)</i> |             |                        |                        |
|-----------------------------------|-------------------------|-------------|------------------------|------------------------|
|                                   | <i>Water</i>            | <i>Soil</i> | <i>Rice<br/>Stalks</i> | <i>Rice<br/>Leaves</i> |
| <i>Low-pesticide-user farm:</i>   |                         |             |                        |                        |
| 0                                 | NDR                     | NDR         | 0.012 ± 0.0070         | 0.020 ± 0.0020         |
| 1                                 | NDR                     | NDR         | 0.028 ± 0.0010         | 0.030 ± 0.0060         |
| 2                                 | NDR                     | NDR         | 0.009 ± 0.0010         | 0.020 ± 0.0040         |
| 3                                 | NDR                     | NDR         | 0.002 ± 0.0005         | 0.009 ± 0.0010         |
| 5                                 | NDR                     | NDR         | NDR                    | 0.005 ± 0.0002         |
| 7                                 | NDR                     | NDR         | NDR                    | NDR                    |
| 15                                | NDR                     | NDR         | NDR                    | NDR                    |
| <i>High-pesticide-user farm:</i>  |                         |             |                        |                        |
| 0                                 | NDR                     | NDR         | 0.030 ± 0.0020         | 0.010 ± 0.0030         |
| 1                                 | NDR                     | NDR         | 0.010 ± 0.0050         | 0.030 ± 0.0100         |
| 2                                 | NDR                     | NDR         | 0.002 ± 0.0010         | 0.010 ± 0.0050         |
| 3                                 | NDR                     | NDR         | 0.002 ± 0.0007         | —                      |
| 5                                 | NDR                     | NDR         | 0.001 ± 0.0005         | 0.001 ± 0.0002         |
| 7                                 | NDR                     | NDR         | NDR                    | NDR                    |
| 15                                | NDR                     | NDR         | NDR                    | NDR                    |

to rainfall washing residues from the leaves into the flood water. Residues were not detected on the rice grains.

Residues of monocrotophos and chlorpyrifos in the air were high at the time of application—that is, about 0.7 mg/m<sup>3</sup> (Table 6.10). This shows that it is unsafe to enter newly pesticide-treated fields about three hours after applications. Although residues were greatly reduced after twenty-four hours, a forty-eight-hour reentry period is safer.

**6.4.1.4. Rapid Field Method Technique.** In the corollary study, the use of the rapid technique for pesticide residue detection gave positive results to the organophosphate insecticides (monocrotophos and chlorpyrifos) tested on floodwater, air, rice plants, and grains. Floodwater collected three hours and one day after treatment with monocrotophos and chlorpyrifos produced positive results, indicating that residue levels were still > 0.05 ug/L. This result means that the ricefield is unsafe for the farmer to enter, particularly if he is barefoot. The

Table 6.10. Residues of Monocrotophos, Chlorpyrifos, and Endosulfan in Some Components of a Rice Paddy Ecosystem at the UPLB Central Experiment Station

| Day                   | Soil (mg/kg)        | Water (mg/l)        | Air (mg/l) |
|-----------------------|---------------------|---------------------|------------|
| <i>Monocrotophos:</i> |                     |                     |            |
| 0                     | 0.002 $\pm$ 0.00005 | 0.002 $\pm$ 0.001   | 0.70       |
| 1                     | ND                  | 0.008 $\pm$ 0.002   | 0.02       |
| 2                     | ND                  | 0.003 $\pm$ 0.000   | ND         |
| 3                     | ND                  | 0.0028 $\pm$ 0.0002 | —          |
| 9                     | ND                  | ND                  | —          |
| <i>Chlorpyrifos:</i>  |                     |                     |            |
| 0                     | 0.59 $\pm$ 0.005    | 0.21 $\pm$ 0.030    | 2.20       |
| 1                     | 0.04 $\pm$ 0.005    | 0.35 $\pm$ 0.050    | —          |
| 3                     | 0.05 $\pm$ 0.003    | 0.42 $\pm$ 0.002    | —          |
| 9                     | —                   | 0.0007              |            |
| 14                    | 0.004 $\pm$ 0.001   | ND                  |            |
| 23                    | ND                  | ND                  |            |
| <i>Endosulfan:</i>    |                     |                     |            |
| 0                     | 0.51                | 1.80                |            |
| 1                     | 0.37                | 2.60                |            |
| 3                     | 0.19                | 0.85                |            |
| 7                     | 0.11                | 0.50                |            |
| 9                     | 0.09                | ND                  |            |

technique developed appears to work well and provides an easy way of determining when it is safe to reenter pesticide-treated fields.

The nylon mesh cloth used to monitor airborne pesticides also showed detectable residues of monocrotophos and chlorpyrifos using the rapid field technique for pesticide residue detection. A very dark blue color confirmed their residues at levels greater than 0.05 ug. This result supports the findings of Tejada and Magallona (1985), where a portion of the applied pesticide goes into the atmosphere of the model ecosystem.

Rice leaves sampled three hours after application of monocrotophos and chlorpyrifos showed positive results that can also be a basis for determining farmers' reentry period into the treated field. Moreover, the method can easily measure levels of residues remaining in the field, which in turn would indicate safe levels (within the MRL) for animals to graze in the field or drink flood-water.

Rice grains stored in jute sacks showed positive residues of malathion for up to five months. Residues were nondetectable thereafter at the minimum detectable limit of 0.05 ug in 5 g of sample. This is within the acceptable daily intake of 0.05 mg/kg for malathion. Based on the performance of the kit in this study, the stored grains in different warehouses can be easily checked for residue levels safe for human or animal consumption.

#### **6.4.2. Pesticide Effect on Algal Population**

A depressive effect of pesticides on algal population was observed on the first three days after the first application in the semi-intensive and high-pesticide-user farms (Figures 6.5a and 6.5b). Recovery was readily achieved on the fourth day, followed by a population bloom. Seven days after pesticide application, algal population had increased by 94 and 366 percent in the semi-intensive and high-pesticide-user farms, respectively, in comparison to preapplication abundance. Subsequent pesticide application reduced algal density to a lesser extent, with a subsequent recovery after three to four days of pesticide application. Depressive effect of pesticide decreased at the advanced stage of the cropping season probably due to the greater “shielding” effect of the rice canopy to the under storey, hence, minimal amount of pesticides reached the floodwater. This observation was consistent for the 1989 WS and the 1990 DS.

In contrast, the stimulatory effect of pesticide on algal density was observed in the low-pesticide-user farm. This was evident after four to six days of application (Figure 6.5c). Algal density increased by 105 percent over the algal population prior to pesticide application. A maximum of 300 percent increase in algal density was observed. One of the probable reasons is that, at low concentration of the pesticides, some of their compounds had stimulatory growth effect on the algae.

A relatively higher algal population was observed in the low-pesticide-user farm while the lowest algal density was observed in the high-pesticide-user farm (Table 6.11). The algal density obtained from the nonpesticide-user farm was not comparable to the other data due to its very acidic soil, while the rest had near basic soils. Algal population distribution differed between the wet and the dry seasons, regardless of treatment. During the 1989 WS, the blue-green algae, diatoms, and green algae were equally distributed in population comprising 30.9, 36.4, and 25.9 percent, respectively. Diatoms predominated during the 1990 DS contributing to 74.98 percent of the total algal population.

Shannon's species diversity index showed significant differences between treatments. The nonpesticide-user farms exhibited the highest species diversity index despite their stressed condition (low pH). The low species diversity index

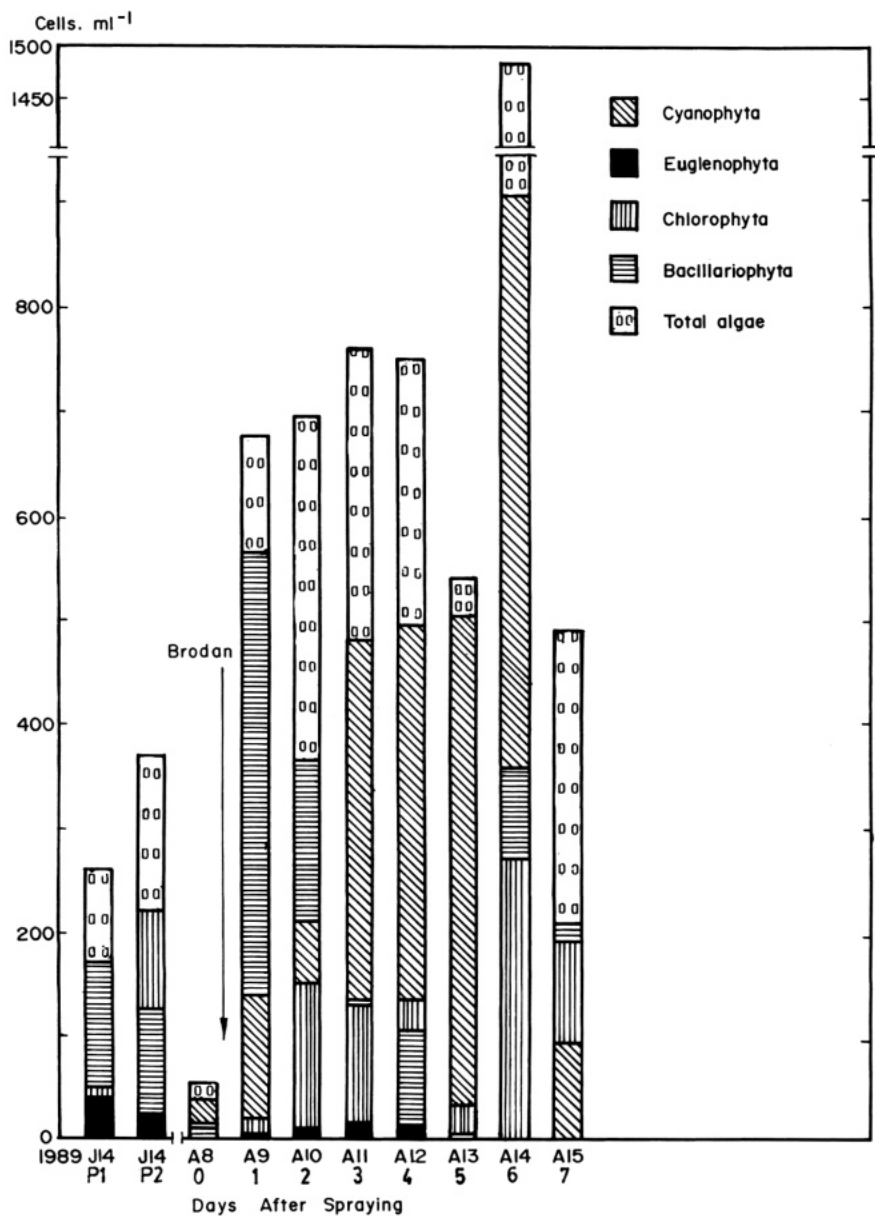


Figure 6.5a. The Fluctuation of Algal Population in a Low-Pesticide-User Farm, Calauan, Laguna, Philippines (1989 WS)

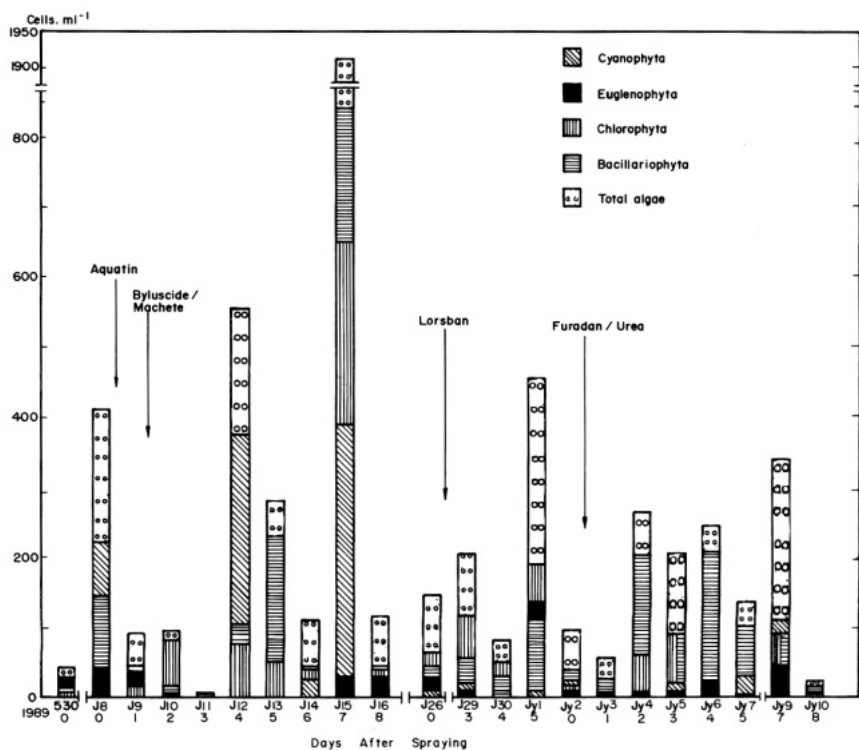


Figure 6.5b. The Fluctuation of Algal Population in a Semi-Intensive-Pesticide-User Farm, Calauan, Laguna, Philippines (1989 WS)

in the low-pesticide-user farms was due to the predominant algal density of *Oscillatoria* species.

#### 6.4.3. Pesticide Effects on Zooplankton

Pesticides applied at high rates temporarily reduced zooplankton counts, but populations recovered quickly. Maximum counts approximately a week after application were 32,000 and 4,000 individuals/sq m in the 1989 WS and 1990 DS, respectively. Populations peaked between three and six days after the application of an organophosphate and then declined. Carbamate applications depressed zooplankton populations in both seasons.

Zooplankton populations in the semi-intensive pesticide-user farm were



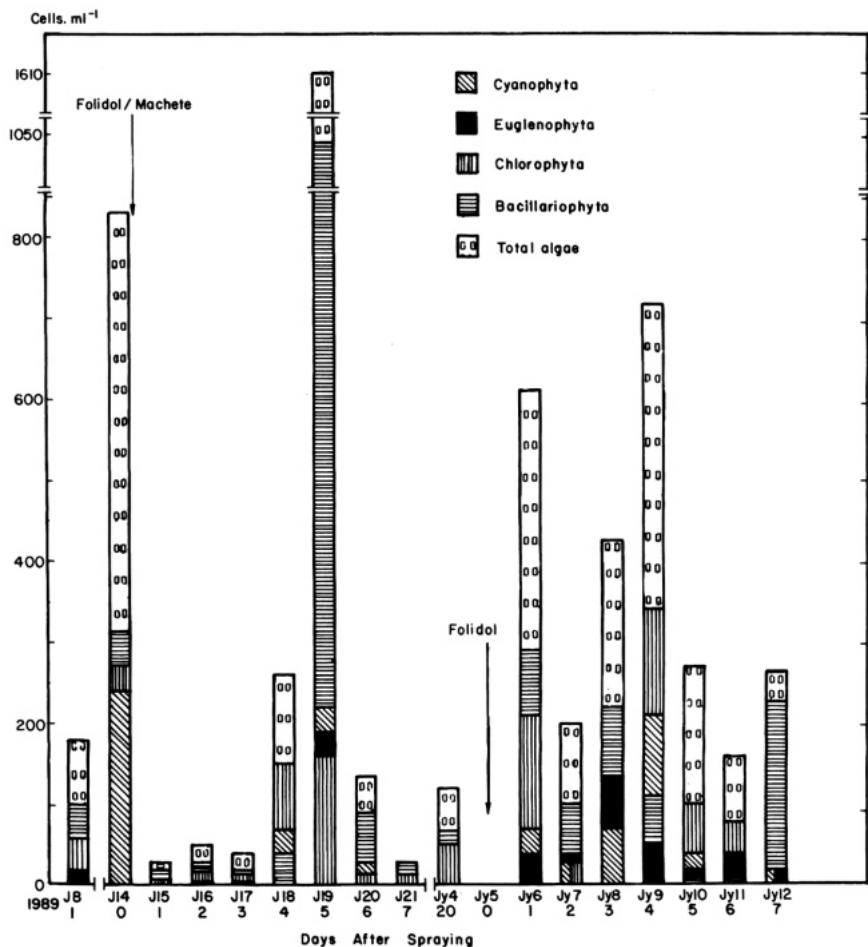


Figure 6.5. The Fluctuation of Algal Population in a High-Pesticide-User Farm, Calauan, Laguna, Philippines (1989 WS)

initially depressed but recovered within four to seven days (1989 WS). Counts declined from an initial 12,000 individuals/sq m to virtually zero one day after application (1990 DS). Zooplankton populations in the low-pesticide-user farm were initially relatively unaffected by the application of chlorpyrifos (1989 WS and 1990 DS), but populations declined by 85 and 90 percent from three to six days after spraying. After the sixth day, populations gradually recovered.

Table 6.11. Effect of the Different Levels of Pesticide Application in Rice Paddies on Algal Population and Diversity Indices (Shannon's H' Diversity index and Simpson's Dominance Index)

| <i>Treatment</i>          | <i>Total Algal Population (units/ml)</i> | <i>Shannon's H' Diversity Index</i> | <i>Simpson's Dominance Index</i> |
|---------------------------|------------------------------------------|-------------------------------------|----------------------------------|
| Nonpesticide <sup>a</sup> | 196.64 c                                 | 1.7726 a                            | 0.1536 b                         |
| Low                       | 573.40 a                                 | 1.2077 c                            | 0.3699 a                         |
| Medium                    | 372.77 b                                 | 1.4584 b                            | 0.2918 b                         |
| Heavy                     | 266.07 c                                 | 1.3402 bc                           | 0.2842 ab                        |

Note: Figures followed by the same letter(s) are not significantly different at  $p = 0.05$  based on Duncan's multiple range test; based on two cropping seasons (1989 WS and 1990 DS).

a. 1991 WS.

## 6.5. Summary and Conclusions

No detectable residues of chlorpyrifos, BPMC, methyl parathion, diazinon, monocrotophos, or endosulfan were found in the rice grains, soil, or animal tissues sampled during the 1989 WS extensive surveys. The absence of detectable residues of these chemicals can probably be explained by their high solubility in water and degradation between application and sampling.

Isoprocab residues were detected in Nile tilapia (*O. niloticus*), "hito" (*C. batrachus*), mudfish (*O. striatus*) and shrimps (*Macrobrachium* sp.). This pesticide is less soluble in water and is easily absorbed through gill surfaces before significant degradation occurs. Isoprocab residues were most concentrated in brain tissues, whereas BPMC was more concentrated in the muscles, kidneys, and heart.

Some evidence was found of chlorpyrifos residues in frogs, chickens, and ducks collected from irrigation canals during the 1990 DS. Residue concentrations were higher in the brain than in other organs. Estimates of average daily intake of chlorpyrifos by the consumption of chicken and ducks were well within the acceptable daily intakes (ADI) set by FAO/WHO.

Monocrotophos and endosulfan residues were recorded in paddy water and soil solution to a depth of 175 cm below the surface. Pesticide degradation and dissipation rapidly reduced the concentrations of both chemicals in the paddy water and surface soil, but small quantities persisted in the deeper soil (125–175 cm) for up to seventy-three days after spraying. Increasing persistence with depth can probably be attributed to decreasing microbial activity.

No evidence of pesticide contamination of well water was found during the

1989 DS; however, traces of monocrotophos, chlorpyrifos, and endosulfan were detected in some samples in the 1989 WS. Acceptable daily intakes (FAO/WHO) of these chemicals were not exceeded when water is considered as the sole source of these chemicals.

The impact of pesticides on the algae was instantaneous as the algal density showed an immediate decline as soon as the pesticides were applied. The greater the frequency of pesticide application, the more depressive was the effect on algal population, regardless of type of algae.

This project pioneers the collection of farmers' field data to establish the behavior of pesticides *in situ* in tropical ricefield ecosystems. Pesticide impacts observed on different components of the ricefield ecosystem ranged from none to inhibitory, to selective or even stimulatory. The nature of the impacts depend on the chemicals, their concentrations, organism sensitivity, and the prevailing environmental conditions.

The majority of the evidence presented suggests that, at least in the short term, pesticide use in ricefields does not represent a significant environmental threat. However, long-term pesticide impacts, particularly residues in fish, deeper soil, and well water, urgently require further investigation.

## Notes

1. Acceptable daily intake (ADI): The daily intake that during an entire lifetime appears to be without appreciable risk to the health of the consumer on the basis of all known facts at the time of the evaluation of the chemicals by the Joint FAO/WHO Meeting on Pesticide Residues. It is expressed in milligrams of the chemical per kilogram body weight.

2. Maximum residue limit (MRL): The maximum concentration of a residue that is legally permitted or recognized as acceptable in or on a food, agricultural commodity or animal feedstuff. The MRLs of the Codex Alimentarius Commission of FAO/WHO reflect the maximum levels likely to occur following the application of a pesticide according to good agricultural practice.

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# 7 THE IMPACT OF RICEFIELD PESTICIDES ON THE QUALITY OF FRESHWATER RESOURCES

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## 7.1. Introduction

In recent years, there have been increasing concerns about the possible contamination of freshwater resources by residues of agrochemicals used on agricultural lands. These concerns stem from the awareness that maintaining the quality of the natural resource base is crucial for sustaining agricultural productivity as well as social progress. However, very little is known about how pesticides used in intensive irrigated rice culture systems, which are practiced in over 40 million hectares in Asia, affect the quality of freshwater resources that receive the excess water from these systems.

The need for insecticide application for controlling pests in modern rice culture has remained a debatable issue for a long time. Ecological considerations clearly demand that pesticide use be reduced, or totally eliminated, if possible. But farmers' perception of the need for pest control is quite different. Although modern rice varieties have some resistance or tolerance to various insects commonly found in ricefields, pesticide use has become a common feature of rice farming even though farmers do not fully understand the hows and whys of such use (Rola and Pingali, 1993). From an optimistic angle one can expect that in the future, as integrated pest management concepts and procedures become widely

used by rice farmers, pesticide use would be reduced. An opposing future scenario is that as rice production is further intensified and higher yields targeted in the presently irrigated areas to meet increasing demands for the cereal, pesticide use in ricefields of Asia may increase. Also, as Rola and Pingali (1993) concluded, there is a concern that where insecticide use is low, poorly implemented integrated pest management programs could increase the amount of insecticide use by farmers.

While there is at least some hope that insecticide use in the future may decline, the prospect for chemical herbicides is different. With the increasing scarcity and cost of rural labor, more and more rice farmers are finding it economically attractive to control weeds by using herbicides. For the same reason, there is a growing popularity of replacing transplanted rice culture with wet-seeded rice culture in which manual or mechanical weed control is very difficult and time-consuming. Furthermore, herbicide availability to farmers has been consistently improving in many countries. All of these developments lead one to conclude that use of herbicides for weed control would continue to increase in many rice-producing countries of Asia.

## **7.2. Pesticide Movement to Freshwater Bodies and Possible Impact**

Only a small fraction of the pesticides applied on ricefields is actually taken up by the plant. The remaining amounts of the applied chemicals are subject to various physicochemical processes for their disposal. Percolation and runoff are two important physical processes determining the fate of pesticides that are in solution in ricefield water. Percolation, which is the vertical movement of water through the soil profile, allows pesticides in solution and adsorbed by entrained sediment to move downward through the soil profile, which may reach the underground water table. Runoff, on the other hand, allows lateral movement of the chemicals along with water away from the ricefield when it is deliberately drained or when excess rainfall or irrigation flow causes overtopping of the field bunds. In a rice irrigation system, all runoff from ricefields are collected in the main drainage system, which ultimately discharges the affluent to a large water body like river, lake, or sea.

While concerns for surface water quality are often separated from those of groundwater quality, the hydrologic cycle provides direct connection between the two in many geologic regions. Depending on hydraulic gradients, surface water may recharge groundwater or be replenished by groundwater (Hicks, Amussen, and Perkins, 1987).

Pesticides resident in drainage water may accumulate in the fresh surface water body to which the drainage system discharges its affluents from the irrigated

ricefields, especially if the pesticides degrade slowly. The impact of such accumulation is far reaching. The water may lose its usefulness as a source of domestic water supply due to the toxicity developed from the pesticides. Aquatic life may be affected. The biggest danger from pesticides in fresh surface water is that they can get into the food chain and affect the health of people and animals consuming the aquatic foods produced in the water body. While acute toxicities cause lethal impact on fish population, sublethal and chronic exposure to pesticides are much more insidious and difficult to identify. Sublethal exposure to pesticides is known to cause suppression in the reproduction success and development of resistant strains in many fish species (Cheng, 1990). Certain aquatic animals have been found to retain (bioaccumulate) pesticides in concentrations many times more than those found in the water. Metcalf, Sangha, and Kpoor (1971) demonstrated that organochlorines such as DDT would be bioaccumulated 10,000 to 100,000 times the level of the chemical in water. Tejada and Magallona (1986) found from a study of rice-fish culture in the Philippines that fish and snails were able to bioaccumulate carbofuran respectively 110 and 10 times the concentration of residues in water. In Surinam, South America, spraying of PCP and endrin on an 8,000 hectare intensive rice-growing region near the coast caused extensive bird and fish kill. Kites foraging in the ricefields accumulated concentrations of PCP approximately 100 times greater than those from nearby freshwater marshes (Vermeer, Risebrough, Spaans, and Reynolds, 1974). The widespread accumulation of pesticides in fish from all over the United States has been well documented (Henderson, Johnson, and Inglis, 1969; Johnson and Lew, 1970; Stucky, 1970; Hunter, Carroll, and Randolph, 1980; Schmitt, Ludke, and Walsh, 1981).

In Asia, the lethal effects of various ricefield pesticides on fish production have been reported by various authors (Lim and Ong, 1977, for Malaysia, and the Punla Foundation, 1981, for the Philippines).

Pesticide contamination of groundwater may render it dangerous for domestic consumption. In rural areas, most rice farmers depend on the abstraction of groundwater from shallow aquifers underneath ricefields for household use. Therefore, pesticides in shallow groundwater are of particular concern. Although much of the pesticides in solution or adsorbed in entrained sediment may be retained in the soil profile as they move downward with percolating water, it is only a matter of time before the adsorption capacity of the soil profile is used up and the pesticides reach the water table and the aquifer. This is specially true for conditions in which intensive rice culture keeps the land saturated for most part of the year. The local hydrology and the type of soil materials that comprise the subsurface profile and the groundwater aquifer mostly determine the extent of pesticides that will leach to the groundwater.

Many studies in the United States (Wartenberg, 1988; Hallberg, 1987; Pionke et al., 1988) and western Europe have detected the presence of pesticides in



groundwater, raising major health concerns. In the United Kingdom, the introduction of highly water soluble herbicides in the 1970s is believed to have caused widespread contamination of groundwater, particularly under the intensive agricultural regions of East Anglia. Some herbicides in groundwater have exceeded the admissible concentrations (Lawrence and Foster, 1987). Localized contaminations have also occurred from the intensive use of insecticides on potatoes and sugar beet grown on permeable soils overlying aquifers. In west European countries, the admissible maximum concentration in groundwater is 0.1 ppb (0.1 µg/L) for a single pesticide and 0.5 ppb (0.5 µg/L) for the sum of multiple pesticides (Leistra and Boesten, 1989). FAO/WHO (1970) set upper limits of concentrations in drinking water for popularly used pesticides based on their toxicity. For example, the acceptable maximum daily intake value for drinking water is 0.0075 mg/kg of body weight (bw) for endosulfan and 0.001 mg/kg-bw for methyl parathion. For butachlor, NRC (1977) of the United States set the upper limit at 0.01 mg/kg-bw for drinking water. The maximum concentration limit for carbofuran, endrin, and lindane are, respectively, 0.04, 0.002 and 0.0002 mg/l (WQA, 1991).

Very few studies have been conducted in the past to investigate the possible contamination of freshwater resources from pesticides used on ricefields. In this paper, two case studies conducted in the Philippines are reported. Case Study 1 addressed the question of pesticide contamination of shallow groundwater resident in aquifers underneath intensively cultivated ricefields. The second study dealt with pesticide concentrations in the drainage affluent from an irrigated area that grows two rice crops in a year.

### **7.3. Case Study 1: Pesticides in Shallow Groundwater Underneath Irrigated Ricelands**

#### **7.3.1. Study Objectives**

The main objectives of this study were to determine (1) whether residues of the commonly used pesticides are present in the shallow groundwater underneath intensively cultivated ricefields and (2) the concentrations of the contaminants present in the water.

#### **7.3.2. Characteristics of the Study Sites**

The study was conducted mainly in the service areas of two irrigation systems—the Upper Pampanga River Integrated Irrigation System (UPRIIS) in Nueva Ecija province and the Sta. Cruz River Irrigation System (SCRIS) in Laguna

province, Philippines. UPRIIS has a total service area of about 90,000 hectares and SCRIS has about 4,000 hectares. A large reservoir supports UPRIIS irrigation. The amount of water stored in the reservoir determines the extent of dry season area that can be irrigated. SCRIS is a run-of-the-river type irrigation system, with no storage facility. Both systems have supported intensive rice culture, with at least two rice crops per year, for over twenty years. Sampling sites were located in three villages within the service area of each irrigation system. For comparison, a 50 to 100 hectare rainfed rice area adjacent to each system was also included in the study. The rainfed area, which did not have access to irrigation supply, grew only one rice crop in the wet season of each year.

### **7.3.3. Methodology**

**7.3.3.1. Selection of Tubewells and Water Sampling Procedure.** A large number of manually operated tubewells used for lifting groundwater from shallow aquifers for domestic use were first identified within the service area of each irrigation system. From them, forty-six tubewells were randomly selected for the study. Of these, thirty-two were within the service area of UPRIIS and fourteen within SCRIS. The rainfed area was sparsely populated, hence fewer samples were available. Four tubewells in the rainfed site near UPRIIS, and three in the site near SCRIS were selected. About 90 percent of the selected tubewells were 6 to 12 m deep, the remaining were 13 to 21 m deep. All tubewells had concrete bases that protected the groundwater from surface contaminants. Water samples were taken from each tubewell once every month following a standard practice of purging the well by pumping water for two to three minutes before collecting about a 4 liter sample in a glass container. Water sampling was done for two consecutive rice-growing seasons, wet season (WS) and dry season (DS), during 1989–1991. The samples were analyzed at the Pesticide Residue Laboratory of International Rice Research Institute (IRRI) using gas chromatography in which the minimum detectable concentration was 0.001 ppb or 0.001 µg/L.

**7.3.3.2. Farmer Surveys.** During each season, fifty-five to sixty-seven randomly selected rice farmers of the study area in UPRIIS and thirty to thirty-five in SCRIS were interviewed for their pesticide use, rice yields, and major agro-nomic practices. Seven rainfed farmers from Laguna and five from Nueva Ecija were also interviewed for the same purpose.

### **7.3.4. Findings and Interpretation**

**7.3.4.1. Pesticide Use in Rice Culture.** The overwhelming popularity of pesticide use in rice culture was clearly evidenced in the farmer response obtained

during the survey. With the exception of one farmer in SCRIS in the WS, all farmers who were interviewed had used pesticides in both seasons (Table 7.1). The farmer who did not use pesticides said that he practiced the integrated pest management (IPM) concept and did not consider it necessary to apply pesticides.

On the whole in the two irrigated rice areas, about 50 percent of annual pesticides used for crop protection was insecticide, 40 percent herbicide, and 10 percent molluscicide.

Compared to UPRIIS, the annual pesticide use in SCRIS was about 25 percent higher due to higher amounts of insecticides and herbicides used in the latter area (Figure 7.1). UPRIIS farmers used more molluscicides because majority of them, 51 percent in the WS and 96 percent in DS, practiced the wet-seeding method of rice crop establishment. At its early stage, wet-seeded rice is more prone to damage by snails, hence the higher molluscicide use in UPRIIS. Higher labor costs and shortage of labor were the main reasons given by farmers for adopting the wet-seeded rice culture in UPRIIS in which land holdings are bigger (Table 7.1).

In the WS, the SCRIS farmers used about 55 percent more pesticides than the adjacent rainfed farmers, higher insecticide use accounting for most of the difference (Figure 7.1). In contrast, UPRIIS farmers used only 15 percent higher amounts of pesticides than the adjacent rainfed farmers and the insecticide uses of the two groups were about the same. Herbicide use in UPRIIS was only 27 percent higher than that in the rainfed area, indicating the growing popularity of herbicide use by farmers even in rainfed, transplanted rice culture.

The total amounts of pesticide use in the two rainfed areas were about the same. But UPRIIS used more insecticides and less herbicides than SCRIS (Figure 7.1). The Nueva Ecija rainfed farms produced higher rice yields than Laguna rainfed farms. The difference could be attributed to the higher nitrogenous fertilizers used by the Nueva Ecija farmers (Table 7.1).

#### **7.3.4.2. Pesticides in Groundwater. *Extent of groundwater contamination.***

Pesticides found in groundwater are considered in two groups. Group A includes those pesticides that were both reported by farmers to have been used during the year and detected in analysis of water samples. Four pesticides are included in this group: butachlor, carbofuran, endosulfan, and methyl parathion. Of these, butachlor is a herbicide, and the others are insecticides. Carbofuran and methyl parathion are considered extremely hazardous and endosulfan moderately hazardous insecticides (Rola and Pingali, 1993). Group B pesticides are those that were detected in water samples but were not reported by the farmer samples to have been used during the year. These are azinphos, DDT, diazinon, endrin, lindane, malathion, and MIPC. Some popularly used pesticides such as pretilachlor

Table 7.1. Farmers' Practices and Rice Yields in Irrigated and Rainfed Rice Areas, Laguna and Nueva Ecija, Philippines

| Site/Season                | Number of<br>Farmers | Average<br>Land<br>Holdings<br>(halfarm) | Crop Establishment |                      | Farmers Using<br>Pesticide<br>(%) | N Use<br>(kg/ha) | Rice<br>Yield<br>(t/ha) |
|----------------------------|----------------------|------------------------------------------|--------------------|----------------------|-----------------------------------|------------------|-------------------------|
|                            |                      |                                          | Wet Seeding<br>(%) | Transplanting<br>(%) |                                   |                  |                         |
| Laguna:                    |                      |                                          |                    |                      |                                   |                  |                         |
| Irrigated area (SCRIS):    |                      |                                          |                    |                      |                                   |                  |                         |
| 1989 WS                    | 30                   | 1.9                                      | 0                  | 100                  | 97                                | 81               | 4.9                     |
| 1990 DS                    | 35                   | 1.8                                      | 0                  | 100                  | 91                                | 111              | 7.8                     |
| Rainfed area: <sup>a</sup> |                      |                                          |                    |                      |                                   |                  |                         |
| 1989 WS                    | 7                    | 3.0                                      | 0                  | 100                  | 100                               | 21               | 2.4                     |
| Nueva Ecija:               |                      |                                          |                    |                      |                                   |                  |                         |
| Irrigated area (UPRIIS):   |                      |                                          |                    |                      |                                   |                  |                         |
| 1990 WS                    | 55                   | 2.7                                      | 51                 | 49                   | 100                               | 78               | 4.3                     |
| 1991 DS                    | 67                   | 2.2                                      | 96                 | 4                    | 100                               | 100              | 6.5                     |
| Rainfed area: <sup>a</sup> |                      |                                          |                    |                      |                                   |                  |                         |
| 1990 WS                    | 5                    | 2.9                                      | 40                 | 60                   | 100                               | 55               | 3.3                     |

a. No DS crops are grown in rainfed farms for lack of irrigation water.

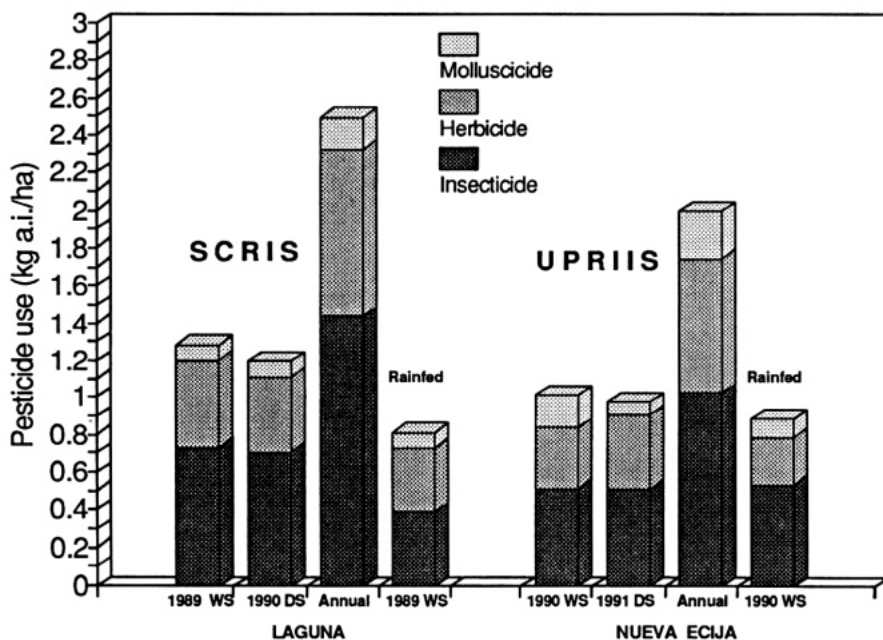


Figure 7.1. Farmers' pesticide use under irrigated and rainfed conditions, Nueva Ecija and Laguna, Philippines

could not be analyzed in the water samples because of limitations in the Laboratory equipment.

Both SCRIS and rainfed area of Laguna had much more prevalence of Group A pesticides than the other two sites in Nueva Ecija. On the average, about 47 percent of the water samples from SCRIS and 36 percent of the samples from the rainfed are contained these pesticides. Endosulfan was the most commonly found (88 percent) pesticide in the water samples of SCRIS during the study year, followed by butachlor (51 percent), methyl parathion (33 percent), and carbofuran (15 percent) (Table 7.2). The same order of prevalence was found in the groundwater samples from the adjacent rainfed area. No carbofuran was found in the water samples of the rainfed area. Butachlor and endosulfan were the two most popularly used pesticides in SCRIS in Laguna. Endosulfan was the most popularly used pesticide by the sample farmers of the Laguna rainfed area (Figure 7.2).

In Laguna, Group B pesticides were found in fewer number of water samples than the Group A pesticides. Lindane (66 percent), DDT (44 percent), and diazinon (32 percent) ranked as the top three in order of prevalence in the

Table 7.2. Percentage of Well-Water Samples with Detectable Concentrations of Pesticides in the Irrigated and Rainfed Rice Areas of Laguna, Philippines

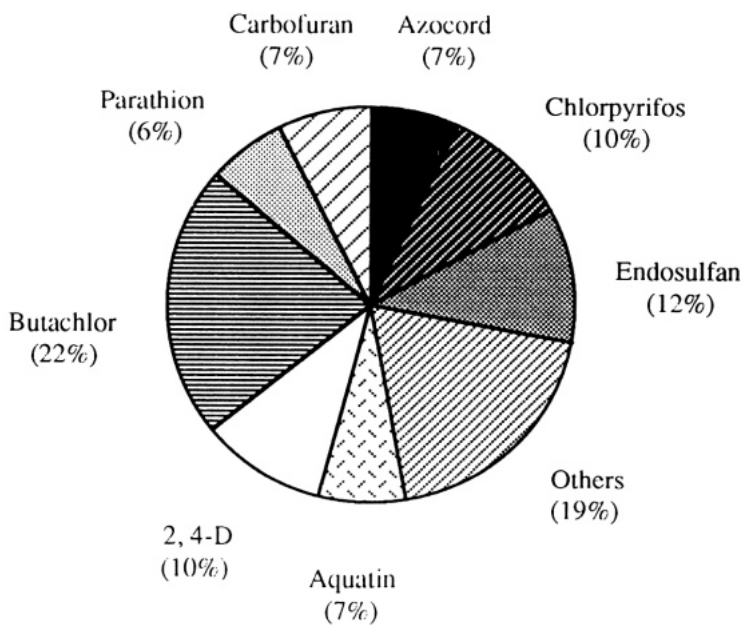
| <i>Pesticides</i> <sup>a</sup> | <i>Irrigated Area (SCRIS)</i>     |                                   |                                   | <i>Rainfed Area</i>              |
|--------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|----------------------------------|
|                                | <i>1989 WS</i><br><i>(n = 42)</i> | <i>1990 DS</i><br><i>(n = 46)</i> | <i>Average</i><br><i>(n = 88)</i> | <i>1989 WS</i><br><i>(n = 9)</i> |
| <i>Group A:</i>                | ----- Percent -----               |                                   |                                   |                                  |
| Butachlor                      | 76.2                              | 26.2                              | 51.2                              | 55.6                             |
| Carbofuran                     | 4.8                               | 24.2                              | 14.5                              | 0                                |
| Endosulfan                     | 97.6                              | 79.2                              | 88.4                              | 77.8                             |
| Methyl parathion               | 49.9                              | 16.4                              | 33.2                              | 11.1                             |
| All                            | 57.1                              | 36.5                              | 46.8                              | 36.1                             |
| <i>Group B:</i>                |                                   |                                   |                                   |                                  |
| Azinphos                       | 26.2                              | 30.9                              | 28.5                              | 33.3                             |
| DDT54.8                        | 32.6                              | 43.7                              | 44.4                              |                                  |
| Diadizon                       | 45.2                              | 17.3                              | 31.8                              | 22.2                             |
| EndM9.5                        | 13.0                              | 11.3                              | 11.1                              |                                  |
| Lindane                        | 73.8                              | 58.7                              | 66.3                              | 44.4                             |
| Malathion                      | 14.3                              | 13.0                              | 13.7                              | 0                                |
| MIPC                           | 38.1                              | 17.4                              | 27.8                              | 22.2                             |
| All                            | 37.4                              | 26.1                              | 31.9                              | 25.4                             |

a. Group A pesticides are those that sample farmers reported to have used and were also found in the water samples. Group B pesticides are those that sample farmers did not report using but were found in the water samples.

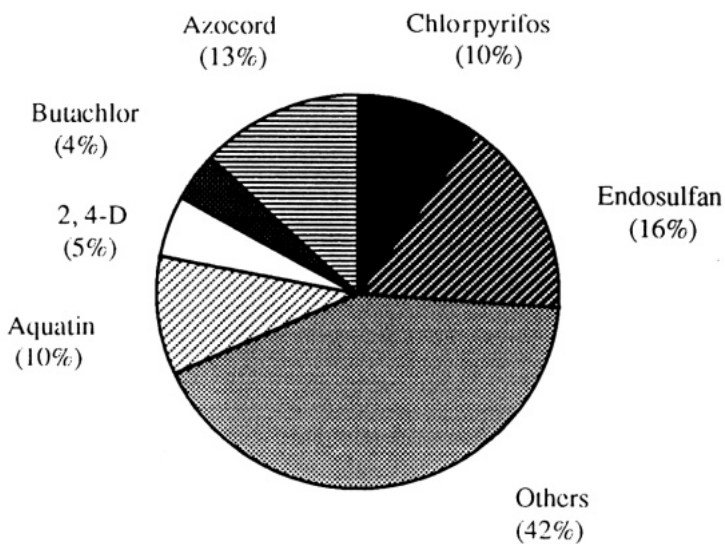
groundwater samples of SCRIS (Table 7.2). In the rainfed area, the first two were most prevalent (44 percent), which was followed by azinphos (33 percent), and diazinon and MIPC (22 percent).

In Nueva Ecija water samples, the prevalence of Group A pesticides was less compared to Laguna. Methyl parathion was found in 35 percent of the water samples from UPRIIS despite its use in 1990–1991 by only one or two farmers (Figure 7.3). Butachlor was detected in 25 percent of all UPRIIS groundwater samples in the WS but none in the DS or the adjacent rainfed area in the WS. Pretilachlor, a preemergence herbicide, was the pesticide most commonly used by the interviewed farmers in both UPRIIS (20 percent) and its adjacent rainfed area (15 percent) (Figure 7.3), but water sample analysis did not include this chemical.

Among the Group B pesticides, diazinon was the most prevalent in the water samples of both UPRIIS (88 percent in WS, 64 percent in DS) and the rainfed



(a)



(b)

Figure 7.2. Farmers' use of various pesticides during 1989 wet and 1990 dry season in (a) SCRIS and (b) adjacent rainfed area

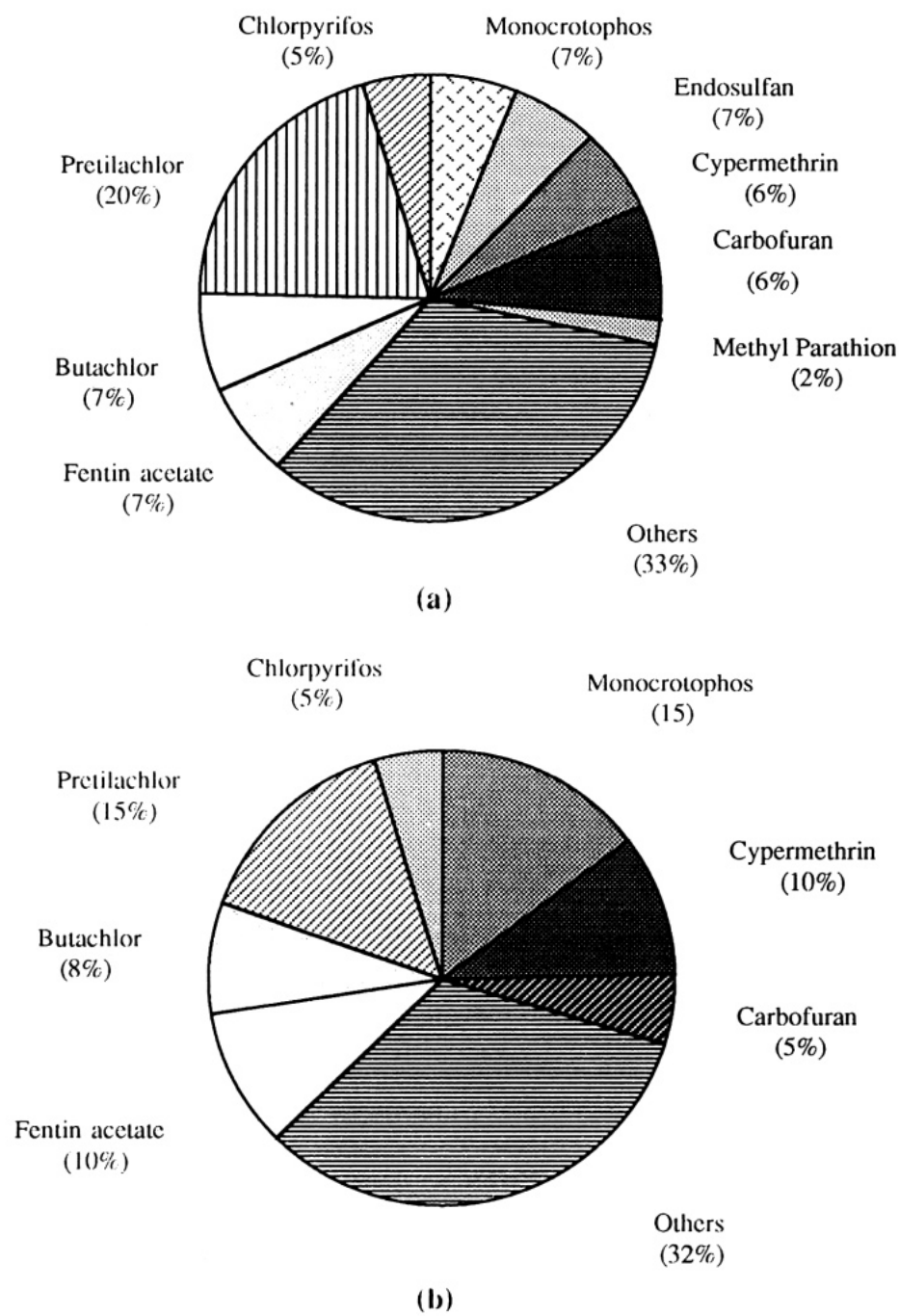


Figure 7.3. Farmers' use of various pesticides during 1990 wet and 1991 dry seasons in (a) UPRIS and (b) adjacent rainfed area



Table 7.3. Percentage of Well-Water Samples with Detectable Concentrations of Pesticides in the Irrigated and Rainfed Rice Areas of Nueva Ecija, Philippines

| <i>Pesticides</i> | <i>Irrigated Area (UPRIIS)</i>     |                                    |                                     | <i>Rainfed Area</i>                |
|-------------------|------------------------------------|------------------------------------|-------------------------------------|------------------------------------|
|                   | <i>1990 WS</i><br>( <i>n</i> = 93) | <i>1991 DS</i><br>( <i>n</i> = 91) | <i>Average</i><br>( <i>n</i> = 184) | <i>1990 WS</i><br>( <i>n</i> = 12) |
| <i>Group A:</i>   | Percent                            |                                    |                                     |                                    |
| Butachlor         | 25.0                               | 0                                  | 12.5                                | 0                                  |
| Carbofuran        | 18.8                               | 0                                  | 9.4                                 | 0                                  |
| Endosulfan        | n.d. <sup>a</sup>                  | n.d.                               | -                                   | n.d.                               |
| Methyl parathion  | 27.5                               | 41.7                               | 34.6                                | 8.3                                |
| All               | 23.8                               | 13.9                               | 18.8                                | 2.8                                |
| <i>Group B:</i>   |                                    |                                    |                                     |                                    |
| Azinphos          | 26.9                               | 37.4                               | 35.0                                | 33.3                               |
| DDTn.d.           | n.d.                               | n.d.                               | n.d.                                |                                    |
| Diazinon          | 88.2                               | 63.7                               | 76.0                                | 83.3                               |
| Endrin n.d.       | n.d.                               | n.d.                               | n.d.                                |                                    |
| Lindane           | 35.5                               | n.d.                               | -                                   | 33.0                               |
| Malathion         | 48.4                               | 8.8                                | 28.6                                | 50.0                               |
| MIPC              | 3.2                                | 0                                  | 1.6                                 | 0                                  |
| All               | 12.5                               | 27.5                               | 28.3                                | 28.5                               |

a. No data; analysis could not be completed due to mechanical problem.

area (83 percent). Malathion was the second most prevalent in water samples of both sites (Table 7.3).

*Pesticide concentration in groundwater.* Among Group A pesticides, the maximum concentration found in the WS water samples of SCRIS was for butachlor (1.14 ppb), with 0.073 ppb as the seasonal mean. Butachlor was found in over three-fourths of the water samples during the season. Although endosulfan was found in nearly all groundwater samples of SCRIS and in 78 percent of the samples from the adjacent rainfed area in the WS (Table 7.2), its mean as well as maximum concentrations in the water were much less than that of butachlor. As in SCRIS, the maximum concentration in Laguna rainfed farms was for butachlor (1.26 ppb), with a seasonal mean of 0.188 ppb (Table 7.4).

In the following DS, the maximum concentration in the SCRIS water samples was for carbofuran (1.15 ppb), with a seasonal mean of 0.095 ppb (Table 7.4). During the season more SCRIS water samples had carbofuran residues than in

Table 7.4. Concentrations of Selected Pesticides in Groundwater Samples Taken from Shallow Aquifers Beneath Irrigated and Rainfed Ricefields, Laguna, Philippines

| Pesticides       | Irrigated Area (SCRIS) |           |                   |           | Rainfed Area |           |
|------------------|------------------------|-----------|-------------------|-----------|--------------|-----------|
|                  | 1989 WS                |           | 1990 DS           |           | 1989 WS      |           |
|                  | Mean                   | Max       | Mean              | Max       | Mean         | Max       |
|                  | (n = 42)               |           | (n = 46)          |           | (n = 9)      |           |
| Group A:         | - - - - -              | - - - - - | Parts per billion | - - - - - | - - - - -    | - - - - - |
| Butachlor        | 0.073                  | 1.140     | 0.075             | 0.380     | 0.188        | 1.260     |
| Carbofuran       | 0.015                  | 0.440     | 0.095             | 1.150     | 0.000        | 0.000     |
| Endosulfan       | 0.051                  | 0.300     | 0.043             | 0.310     | 0.033        | 0.100     |
| Methyl parathion | 0.023                  | 0.130     | 0.009             | 0.230     | 0.010        | 0.090     |
| All              | 0.041                  | 0.503     | 0.056             | 0.518     | 0.058        | 0.363     |
| Group B:         |                        |           |                   |           |              |           |
| Azinphos ethyl   | 0.025                  | 0.210     | 0.025             | 0.320     | 0.040        | 0.240     |
| DDT              | 0.010                  | 0.020     | 0.003             | 0.020     | 0.007        | 0.020     |
| Diazinon         | 0.038                  | 0.460     | 0.004             | 0.072     | 0.017        | 0.140     |
| Endrin           | 0.006                  | 0.101     | 0.003             | 0.072     | 0.001        | 0.038     |
| Lindane          | 0.002                  | 0.010     | 0.004             | 0.016     | 0.001        | 0.004     |
| Malathion        | 0.004                  | 0.070     | 0.003             | 0.072     | 0.000        | 0.000     |
| MIPC             | 0.034                  | 0.260     | 0.009             | 0.150     | 0.007        | 0.050     |
| All              | 0.017                  | 0.162     | 0.007             | 0.103     | 0.012        | 0.082     |

the previous season, but the prevalence of the other three pesticides decreased. Endosulfan, however, remained by far the most prevalent pesticide during the season (Table 7.2). All seven pesticides of Group B were present in the DS water samples of SCRIS and those of the 1989 WS from the rainfed area, but at much lower concentrations than those of Group A pesticides (Table 7.4).

The maximum concentration of the Group A pesticides in the water samples of UPRIIS in 1990 WS was for carbofuran (1.064 ppb), with a seasonal mean concentration of 0.055 ppb (Table 7.5). In the following DS, the only pesticide that was detected in the UPRIIS water samples was methyl parathion, with a maximum concentration of 0.042 ppb and a seasonal average of 0.007 ppb. Methyl parathion was detected in 42 percent of the groundwater samples during the season (Table 7.3). In general, pesticide concentrations, both maximum and seasonal average, were much less in UPRIIS compared to SCRIS.

Table 7.5. Concentrations of Selected Pesticides in Groundwater Samples Taken from Shallow Aquifers Beneath Irrigated and Rainfed Ricefields, Nueva Ecija, Philippines

| <i>Pesticides</i> | <i>Irrigated Area (UPRIIS)</i> |            |                          |            | <i>Rainfed Area</i>      |            |
|-------------------|--------------------------------|------------|--------------------------|------------|--------------------------|------------|
|                   | <i>1990 WS</i>                 |            | <i>1991 DS</i>           |            | <i>1990 WS</i>           |            |
|                   | <i>Mean<br/>(n = 93)</i>       | <i>Max</i> | <i>Mean<br/>(n = 91)</i> | <i>Max</i> | <i>Mean<br/>(n = 12)</i> | <i>Max</i> |
| <i>Group A:</i>   | ----- Parts per billion -----  |            |                          |            |                          |            |
| Butachlor         | 0.009                          | 0.098      | 0.000                    | 0.000      | 0.000                    | 0.000      |
| Carbofuran        | 0.055                          | 1.064      | 0.000                    | 0.000      | 0.000                    | 0.000      |
| Endosulfan        | n.d. <sup>a</sup>              | n.d.       | n.d.                     | n.d.       | n.d.                     | n.d.       |
| Methyl parathion  | 0.002                          | 0.052      | 0.007                    | 0.042      | 0.001                    | 0.008      |
| All               | 0.022                          | 0.405      | 0.002                    | 0.013      | 0.000                    | 0.003      |
| <i>Group B:</i>   |                                |            |                          |            |                          |            |
| Azinphos ethyl    | 0.025                          | 0.120      | 0.024                    | 0.892      | 0.004                    | 0.234      |
| DDT               | n.d.                           | n.d.       | n.d.                     | n.d.       | n.d.                     | n.d.       |
| Diazinon          | 0.038                          | 0.060      | 0.012                    | 0.034      | 0.027                    | 0.045      |
| Endrin            | n.d.                           | n.d.       | n.d.                     | n.d.       | n.d.                     | n.d.       |
| Lindane           | 0.007                          | 0.220      | n.d.                     | n.d.       | n.d.                     | n.d.       |
| Malathion         | 0.014                          | 0.132      | 0.004                    | 0.020      | 0.012                    | 0.060      |
| MIPC              | 0.001                          | 0.036      | n.d.                     | n.d.       | n.d.                     | n.d.       |
| All               | 0.012                          | 0.081      | 0.013                    | 0.315      | 0.014                    | 0.113      |

a. No data; analysis could not be completed due to mechanical problems.

The mean concentrations of Group B pesticides did not vary much across sites or seasons; however, individual pesticide concentrations were generally lower than those of Group A pesticides in the water samples of both irrigation systems. Azinphos was found in relatively high maximum concentrations in the water samples of both irrigated sites, especially in UPRIIS in the DS. DDT and endrin were found in water samples of SCRIS and Laguna rainfed areas in both seasons, but not in the samples of UPRIIS (Tables 7.4 and 7.5). As in the case with many other countries in Asia, DDT and endrin are banned for agricultural use in the Philippines (ADB, 1987). Azinphos and endrin are considered highly hazardous pesticides (Rola and Pingali, 1993).

Most pesticides used for crop protection have half-lives from a few days to a few months in the soil-water system exposed to the normal environmental conditions, but their persistence in the conditions groundwater normally occurs

may be a different story. Little is known about the pesticide degradation process in groundwater that is not exposed to the physical, atmospheric, and biological forces that degrade pesticides. Therefore, it is difficult to directly associate the prevalence of pesticides in groundwater samples to their most recent use by farmers of the vicinity because it may take many years for some pesticides to reach groundwater. Similarly, it is not possible to conclude whether the prevalence of Group B pesticides is associated with their most recent use by nonsample farmers, or with previous use by farmers, or both. Although usually at a very slow rate, groundwater is always on the move laterally; therefore one should not also strongly associate the prevalence of pesticides in groundwater at a specific location to their use in that location.

**7.3.4.3. The Role of Hydraulic Property of Soil.** Of the different factors that independently and interactively determine the downward movement of chemicals applied on the water above the surface, soil texture is a main factor due to its influence on the hydraulic property of the soil. Because of the presence of more macropores in them, sandy soils allow water infiltration and percolation at faster rates than clay soils. Therefore, pesticides applied on ricefield water would move downward more readily in sandy soils. Furthermore, in sandy soils the adsorption of the chemical is less. In the United States, the most susceptible sites for pesticide contamination of groundwater have been identified as those with sandy soils, shallow water tables and high rates of infiltration, together with low soil organic carbon content (Lawrence and Foster, 1987). Some previous studies on the movement of nitrate-nitrogen from fertilizer applied on the ricefield water to groundwater table has been explained by the hydraulic property of the soil (Spalding, Junk, and Richard, 1980; Castañeda and Bhuiyan, 1991).

SCRIS soils have loamy sand to clay textures, with an average percolation rate of 7.5 mm/day. In contrast, UPRIIS soils have silty clay loam to clay textures and an average percolation rate of 4.9 mm/day. The difference in the hydraulic property of SCRIS and UPRIIS soils may have contributed to the presence of pesticides in a higher proportion of groundwater samples and in higher concentrations in SCRIS.

## **7.4. Case Study 2: Ricefield Pesticides in Runoff Draining into a Freshwater Body**

### **7.4.1. Objective of the Study**

This study complements the Sta. Cruz River Irrigation (SCRIS) component of Case Study 1, which has been presented above. The primary objective pursued

in this investigation was to determine whether pesticides applied on ricefields are present in the drainage outflows from SCRIS before they leave the system boundary and discharge into the lake called Laguna de Bay.

#### *7.4.2. Characteristics of the Study Site*

SCRIS's irrigation and rice culture background has been discussed in relation to Case Study 1. The system, which has been in operation since 1953, supports two rice crops grown in a year in its service area of about 4,000 hectares. Its DS irrigated area, however, varies from year to year because there is no storage reservoir supporting the system and therefore DS rice culture is largely dependent on the river flow. SCRIS receives a total yearly rainfall of about 2,000 mm, about 20 percent of which is received in the DS. The drainage effluents of the system and the nearby areas discharge into the Laguna de Bay, a very large freshwater lake on the edge of which SCRIS is located.

#### *7.4.3. Methodology*

A contiguous, hydrologically bound rice area of about 500 hectares within the service area of SCRIS was selected for this study. The nearly hexagonal area was bounded by roads on five sides and the main irrigation canal on the other. For comparison, rainfed area of about 50 hectares outside of SCRIS service area was chosen. This area grows only one crop of rice in the WS of each year.

Through field survey, three drainage water outflow points and one irrigation water inflow point, which controlled the water inflow-outflow process of the selected area, were identified. At each of these points water samples were collected in 4-liter glass bottles three times during each of 1989 WS and 1990 DS for pesticide analysis. Drainage outflows from the rainfed area were also collected at the same time for pesticide analysis. The analysis was conducted in the Pesticide Residue Laboratory of IRRI, using the gas chromatography technique. The minimum detection level for the method was 0.001 ppb.

At the end of each season, thirty randomly selected rice farmers from within SCRIS service area were interviewed in 1989 WS and thirty-five in 1990 DS to obtain information on the type and extent of their pesticide use and on rice culture. From the rainfed area, seven randomly selected farmers were interviewed for the same information.

#### *7.4.4 Results and Discussion*

**7.4.4.1. Agrochemicals Used and Yields Obtained.** In the WS, SCRIS farmers used slightly higher amounts of pesticides (average 1.29 kg ai/ha) compared

Table 7.6. Farmer's Agrochemical Use in Ricefields Under Irrigated Conditions, Laguna, Philippines

|                          | <i>Irrigated Area (SCRIS)</i> |                |             | <i>Rainfed Area</i> |
|--------------------------|-------------------------------|----------------|-------------|---------------------|
|                          | <i>1989 WS</i>                | <i>1990 DS</i> | <i>Mean</i> | <i>1989 WS</i>      |
| Fertilizer use (kg Nha)  | 81 [1001]                     | 111 [100]      | 86 [1001]   | 21 [1001]           |
| Urea                     | 70.2 (87)                     | 93.3 (84)      | 81.8 (86)   | 20.1 (96)           |
| 14-14-14                 | 8.6 (11)                      | 13.8 (13)      | 11.2 (12)   | 0 (0)               |
| Others                   | 2.2 (2)                       | 3.9 (3)        | 3.1 (2)     | 0.9 (4)             |
| Pesticide use (kg ai/ha) | 1.29 [97]                     | 1.21 [90]      | 1.3 [94]    | 0.82 [1001]         |
| Insecticide              | 0.73 (57)                     | 0.71 (59)      | 0.72 (58)   | 0.39 (48)           |
| Herbicide                | 0.48 (37)                     | 0.41 (34)      | 0.45 (35)   | 0.34 (42)           |
| Molluscicide             | 0.08 (6)                      | 0.09 (7)       | 0.08 (7)    | 0.09 (10)           |
| Rice yield (t/ha)        | 4.88                          | 7.77           | 2.35        |                     |

Note: Figures in [] are percent of interviewed who applied agrochemicals. Figures in () are percent of specific agrochemical use.

to the DS (average 1.21 kg ai/ha). The rainfed farmers applied less pesticides in the WS, which averaged 0.82 kg ai/ha (Table 7.6).

Of the pesticides applied during the two seasons, about 58 percent was insecticides, 35 percent herbicides, and 7 percent molluscicides. The average amounts of the three types of pesticides used within the SCRIS area were about the same between the two seasons. All rainfed area farmers used pesticides in their WS rice. In SCRIS, only one farmer in WS and three in DS did not apply pesticides because they practiced the integrated pest management concept and did not consider it necessary to use pesticides.

Rice yields in SCRIS were about 60 percent higher in the DS than in the WS, which could be mostly due to the higher amounts of fertilizer use and solar radiation in the DS. In the WS, rainfed area averaged only 2.35 t/ha yield, which was less than half of the average yield of irrigated rice. Once again, the difference could be attributed to the higher fertilizer use and irrigation water inputs in the SCRIS farms (Table 7.6).

The most commonly used pesticides are listed in Table 7.7. However, due to limitations in available facilities, analysis of irrigation inflow and drainage outflow samples for pesticide residues was conducted for only four commonly used pesticides. These are endosulfan, methyl parathion, carbofuran, and butachlor. The first three are insecticides, and the last one is a herbicide.

**7.4.4.2. Pesticides in Irrigation and Drainage Water.** In the WS, the highest pesticide concentration found was 0.54 ppb for carbofuran in irrigation water

Table 7.7. Percentage of Total Pesticide Used in Ricefields Under Irrigated and Rainfed Conditions, Laguna, Philippines

|                              | <i>Irrigated Area (SCRIS)</i> |                |               | <i>Rainfed Area</i> |
|------------------------------|-------------------------------|----------------|---------------|---------------------|
|                              | <i>1989 WS</i>                | <i>1990 DS</i> | <i>Annual</i> | <i>1989 WS</i>      |
| Insecticide:                 | — — — — —                     | — — — — —      | —Percent—     | — — — — —           |
| Monocrotophos                | 1.2                           | 7.0            | 4.1           | 5.2                 |
| Endosulfan                   | 9.3                           | 12.2           | 10.7          | 15.6                |
| Chlorpyrifos                 | 13.2                          | 6.6            | 9.8           | 10.4                |
| Methyl parathion             | 5.4                           | 7.0            | 6.2           | 0.0                 |
| Carbofuran                   | 5.4                           | 8.1            | 6.8           | 0.0                 |
| Cypermethrin + monocrotophos | 10.9                          | 3.7            | 7.2           | 13.0                |
| Herbicide:                   |                               |                |               |                     |
| Butachlor                    | 21.7                          | 22.5           | 26.8          | 3.9                 |
| 2,4-D13.6                    | 7.0                           | 10.2           | 5.2           |                     |
| Propanil                     | 0.0                           | 0.0            | 0.0           | 26.0                |
| Molluscicide:                |                               |                |               |                     |
| Aquatin                      | 7.0                           | 7.4            | 7.2           | 10.4                |
| Fentin acetate               | 0.0                           | 0.0            | 0.0           | 10.3                |
| Others <sup>a</sup>          | 12.3                          | 18.5           | 11.0          | 0.0                 |
| Total                        | 100                           | 100            | 100           | 100                 |

a. Minor application of twenty-three other pesticides in SCRIS.

and 3.46 ppb for methyl parathion in drainage water (Table 7.8). Their average concentrations for the three sampling times in the season were much lower. In the rainfed area, the maximum concentration found for drainage outflow was for butachlor (0.230 ppb). There was no carbofuran detected in drainage outflow. In the DS, the maximum concentration in irrigation inflow was for endosulfan (0.08 ppb) compared to 1.99 ppb of carbofuran in the drainage water (Table 7.9). In both seasons, the average pesticide concentration in drainage water was much higher for all pesticides (except butachlor in WS when the concentrations were about equal) than that in irrigation water, which implies that farmer-applied pesticides on the ricefields were transported to drainage water. Although the amounts of pesticide use between the two seasons were about the same, higher runoff of ricefield water into the drainage system in the WS, which was caused by higher rainfall, is the likely reason for the higher maximum and average pesticide concentrations in the WS. In the rainfed area, where farmers used much less pesticide, the highest pesticide concentration in drainage water was much lower, 0.23 ppb.

Table 7.8. Pesticide Concentrations in Irrigation and Drainage Waters Under Irrigated and Rainfed Conditions, 1989 WS, Laguna, Philippines

| Sampling month/<br>Pesticide | Irrigated Area (SCRIS) |                   |       |       |       | Rainfed Area        |
|------------------------------|------------------------|-------------------|-------|-------|-------|---------------------|
|                              | Irrigation<br>Inflow   | Drainage Outflow  |       |       |       | Drainage<br>outflow |
|                              |                        | 1                 | 2     | 3     | Mean  |                     |
| August 1989:                 | - - - - -              | Parts per billion |       |       |       | - - - - -           |
| Endosulfan                   | 0.010                  | 0.020             | 0.020 | 0.100 | 0.047 | 0.010               |
| Butachlor                    | 0.120                  | 0.270             | 0.220 | 0.210 | 0.233 | 0.230               |
| Methyl parathion             | 0.000                  | 0.000             | 0.000 | 0.020 | 0.007 | 0.000               |
| Carbofuran                   | 0.000                  | 0.460             | 0.0   | 1.910 | 0.790 | 0.000               |
| September 1989:              |                        |                   |       |       |       |                     |
| Endosulfan                   | nw                     | 0.029             | 0.141 | nw    | 0.057 | 0.100               |
| Butachlor                    | nw                     | 0.200             | 0.000 | nw    | 0.067 | 0.210               |
| Methyl parathion             | nw                     | 0.000             | 0.180 | nw    | 0.090 | 0.000               |
| Carbofuran                   | nw                     | 0.000             | 0.000 | nw    | 0.000 | 0.000               |
| November 1989:               |                        |                   |       |       |       |                     |
| Endosulfan                   | 0.010                  | 0.010             | 0.001 | *     | 0.005 | 0.010               |
| Butachlor                    | 0.190                  | 0.000             | 0.320 | 0.320 | 0.106 | 0.030               |
| Methyl parathion             | 0.010                  | 3.460             | 0.050 | 0.000 | 1.170 | 0.010               |
| Carbofuran                   | 0.540                  | 0.220             | 1.050 | 0.040 | 0.437 | 0.000               |

Note: nw = no water sample; \* = missing data.

7.5. Conclusions

From Case Study 1, there is clear evidence that in both sites groundwater in the shallow aquifers underneath intensively cultivated irrigated ricefields are receiving a large number of pesticides used by farmers for crop protection. Some of these pesticides are considered extremely hazardous. Although seasonal mean concentrations for individual pesticides in groundwater were much lower than the maximum concentrations detected, a major concern is the multiple toxicity. For example, in SCRIS the WS total of mean toxicity of the eleven pesticides in water samples was 0.283 ppb which is not very far from the maximum concentration of 0.500 ppb that is permissible in drinking water. Furthermore, there are other pesticides that farmers reported using, for which no analysis was conducted. Since in the rural areas water supply for domestic purposes is obtained mostly from shallow groundwater aquifers, the importance of maintaining their quality can hardly be overemphasized.

The process of pesticide movement to groundwater and pesticide persistence



Table 7.9. Pesticide Concentrations in Irrigation and Drainage Waters from Irrigated Ricefields, SCRIS, Laguna, Philippines, 1990 DS

| Sampling Month /<br>Pesticide | Irrigation<br>Inflow | Drainage outflow            |       |       | Mean      |
|-------------------------------|----------------------|-----------------------------|-------|-------|-----------|
|                               |                      | 1                           | 2     | 3     |           |
| January 1990:                 | - - - - -            | Parts per billion - - - - - |       |       | - - - - - |
| Endosulfan                    | 0.023                | 0.191                       | 0.418 | 0.311 | 0.307     |
| Butachlor                     | 0.000                | 0.040                       | 0.000 | 0.010 | 0.017     |
| Methyl parathion              | 0.000                | 0.000                       | 0.000 | 0.000 | 0.000     |
| Carbofuran                    | 0.000                | 0.100                       | 0.000 | 1.990 | 0.697     |
| February 1990:                |                      |                             |       |       |           |
| Endosulfan                    | 0.080                | 0.070                       | 0.220 | 0.030 | 0.107     |
| Butachlor                     | 0.000                | 0.000                       | 0.000 | 0.000 | 0.000     |
| Methyl parathion              | 0.000                | 0.000                       | 0.000 | 0.000 | 0.000     |
| Carbofuran                    | 0.000                | 0.130                       | 0.000 | 0.100 | 0.077     |
| April 1990:                   |                      |                             |       |       |           |
| Endosulfan                    | nw                   | 0.600                       | nw    | 0.000 | 0.200     |
| Butachlor                     | nw                   | 0.000                       | nw    | 0.000 | 0.000     |
| Methyl parathion              | nw                   | 0.000                       | nw    | 0.000 | 0.000     |
| Carbofuran                    | nw                   | 0.000                       | nw    | 0.210 | 0.070     |

Note: nw = no water sample.

in groundwater are not fully understood. In-depth investigations are needed in order to predict the immediate and long-term impact of changes in pesticide use on groundwater quality.

Currently, there is a lack of clarity about the permissible concentrations of different categories of pesticides, especially the new generation pesticides, in drinking water. There is no clear guideline for the multiple-pesticides situation. Strict guidelines from concerned government agencies are needed, along with stronger practical measures to reduce the hazard of pesticide toxicity in natural water bodies. Long-term networks for monitoring water quality impacts of pesticides used for crop protection within major irrigation systems should be established.

Case Study 2 indicates that the drainage outflows of SCRIS and the nearby rainfed areas of Laguna are discharging some of the pesticides used on the ricefields into the freshwater body of Laguna de Bay. Both highly hazardous pesticides such as methyl parathion and carbofuran, and moderately hazardous pesticides such as endosulfan are present in the drainage water that discharges into the lake. The Philippine Department of Environment and Natural Resources (DENR) (1990) allows no toxicity from organophosphates such as methyl parathion in any kind of freshwater body because of health hazards of the

chemicals. From this study it is not possible to predict how much of the pesticides in the drainage water would naturally degrade in the process of their transport to the lake or when they are mixed with the lake water, and how much would remain in the freshwater. Therefore, no conclusions can be drawn as to the potential of these residues in drainage water for toxifying the freshwater of the lake.

In the past the Laguna Lake Development Authority (LLDA) found that many pesticides in lake water exceeded the maximum permissible levels for propagation of fish and aquatic resources (NPCC, 1978). LLDA also claimed that there is a reservoir of pesticides contained in the bottom mud of the lake. Edwards (1974) indicated the presence of such an accumulation phenomenon in lakes because pesticides have the tendency to get adsorbed into the bottom sediments on reaching the body of water due to their affinity for organic matter. A cumulative process of pesticide buildup in Laguna de Bay would create an extremely hazardous condition for the aquatic life in the lake and attendant health hazards for humans. Intensive scientific monitoring of the lake water quality as affected by the quality of effluents discharged into the lake should be conducted on a long-term basis.

In the Philippines there is no clear policy at this time for pesticide concentrations in effluents from various sources discharging to freshwater bodies. Without such standards, it will be impossible to regulate the water quality of such water bodies with respect to pesticide toxicity and pollution from various sources.

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# 8 THE IMPACT OF PESTICIDES ON RICEFIELD VERTEBRATES WITH EMPHASIS ON FISH

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## 8.1. Introduction

Production of fish on rice farms, traditionally practiced in Asian countries, is considered by policymakers as a viable option for sustaining food production in lowland areas, augmenting farm income and improving the quality of food available to Asian farm households. Rice-fish farming systems hence represent an ideal practice for more efficient utilization of agricultural resources in lowland rice areas (Fagi Suriapermana and Syamsiah, 1989). In the Philippines, for example, the 1.5 million hectares of irrigated land planted to high-yielding rice varieties can produce 300,000 tons of tilapia or a combination of tilapia and common carp per year, or over 2.5 times the recorded volume of production from fish ponds. As such, rice-fish culture can potentially boost national fish production by at least 20 percent (Samson, 1979).

The use of pesticides has been reported to have caused a decline in the practice of rice-fish culture in some parts of Central Thailand in the 1970s (Spiller, 1985), Indonesia in 1968–1969 (Koesoemadinata, 1980 Saanin, 1960), Malaysia in 1972 (Lim and Seng-Hock, 1985), and Vietnam (Vincke, 1979). Annual application of around 2 kg per hectare of insecticide was reported to have caused financial losses in rice-fish culture in Indonesia (Hardjamulia and

Table 8.1. Development Potential of Rice-Fish Culture in Asia

| Country     | <i>Development Potential</i> |                        | Remarks                                                                                                     |
|-------------|------------------------------|------------------------|-------------------------------------------------------------------------------------------------------------|
|             | <i>Traditional</i>           | <i>High Production</i> |                                                                                                             |
| Bangladesh  | S2                           | S3                     | Both countries lack inputs (manure, rice bran) but deepwater rice areas have potentials; wild fish abundant |
| Burma       | S1                           | S2                     |                                                                                                             |
| China       | S1                           | S2                     |                                                                                                             |
| India       | S3                           | S3                     | High financial incentives and good extension program                                                        |
| Indonesia   | S1                           | S1                     | Low demand for fish is a constraint                                                                         |
| Kampuchea   | S3                           | N                      | Good financial incentives                                                                                   |
| Korea       | N                            | S3                     | Lack of inputs                                                                                              |
| Laos        | S3                           | N                      | High use of agrochemicals; limited water                                                                    |
| Malaysia    | N                            | S3                     | Lack of inputs                                                                                              |
| Nepal       | S2                           | S3                     | Heavy pesticide use                                                                                         |
| Pakistan    | N                            | N                      | Lack of inputs; low demand                                                                                  |
| Philippines | S3                           | S3                     | Low demand for small fish; low water level in paddy                                                         |
| Sri Lanka   | S3                           | S3                     | High use of agrochemicals                                                                                   |
| Thailand    | S1                           | S3                     | Hilly areas; low water level in paddy field                                                                 |
| Vietnam     | S2                           |                        | Good potential for traditional systems; field not drained for weeding                                       |
|             |                              |                        | Lack of inputs but good control of pesticide use                                                            |

Source: Spiller (1985).

Note: Legend for development potential: S1 = high, S2 = good, S3 = fair, N = not suitable at this time.

Koesoemadinata, 1972; Saanin, 1960). Similarly, a 67 percent decline in paddy fish production since 1972 was attributed to increased pesticide use in Malaysia (Spiller, 1985). In the Philippines, some farmers reported detrimental effects of pesticides to fish, but no data is available to substantiate such claims. In general, the potential and constraints for rice-fish culture in some Asian countries are summarized by Spiller (1985) in Table 8.1. While potentials include good financial incentives, constraints range from lack of inputs and demand for fish to heavy use of agrochemicals especially pesticides. Among the Asian countries reviewed,

Korea, Malaysia, and the Philippines are reported to be heavy users of agricultural pesticides.

Rice-fish farming in the Philippines was introduced only in 1974 and is still at the experimental (field-testing and verification) stage. Its small-scale adoption is partly influenced by technological and social constraints such as the use of high-yielding varieties associated with indiscriminate use of pesticides and shorter rice production cycle resulting in smaller fish size at harvest, unavailability of fingerlings, inadequate water supply, fish poaching, and the risk-averse attitude of most rice farmers (Ahmed, Bimbao and Sevilleja, 1992).

The two main constraints to increased productivity in irrigated rice-fish farming systems, however, are water control and pesticide use. The latter is considered the more serious constraint because it can be justified in areas where potential rice yields are also high (Waibel, 1992).

Since fish must generally adapt to management practices for rice, information on toxicity, degradation, and residues of pesticides in fish are imperative for the development of a better symbiotic relationship between rice and fish in an integrated farming system. Acute toxicity parameter  $LC_{50}^1$  provides information on the effect of pesticides in extreme conditions and may serve as a basis for field application rates safe for fish. Degradation period of pesticides meanwhile indicate the "safe" period to stock fish. Pesticide residue data in fish are currently few but remain essential for the safe use of pesticides in rice-fish culture. These information are presented and reviewed in Cagauan and Arce (1992) and will be used in subsequent discussions.

#### 8.1.1. *Pesticide use in Nueva Ecija, Philippines*

This section provides brief information on the levels of pesticide used in Nueva Ecija, Philippines, where some rice farmers have begun adopting rice-fish farming. The information herein is discussed in detail in Chapter 3 of this book and in Rola and Pingali (1993).

The share of pesticides in total rice and vegetable production costs has been rising over time, primarily due to the increasing number of applications made per season. Insecticide applications per season for Nueva Ecija increased from one to three in the late 1970s to one to six in the 1980s.

An increasing number of applications, however, have occurred without a consequent increase in total active ingredient of insecticide applied per hectare, which has remained virtually constant between 1978 and 1989. In the dry season, Nueva Ecija farmers applied insecticides at an average of 1.78 kg ai/ha in 1979, 1.36 kg ai/ha in 1985, 1.46 kg ai/ha in 1988, and 1.57 kg ai/ha in 1,989. This dramatically decreased to 0.78 kg ai/ha in 1991. In the wet season,

insecticides were applied at 1.78 kg ai/ha in 1979 and at 1.39 kg ai/ha in 1985. While the same trend can be observed with herbicide use, farmer application of molluscicides in the dry season increased from 0.51 kg ai/ha in 1989 to 0.62 kg ai/ha in 1991.

Rice farmers in Nueva Ecija use more organochlorines (OC) and organophosphates (OP) than carbamates and pyrethroids. OC and OP are in the World Health Organization (WHO) hazardous categories I and II. Endrin and endosulfan were the most commonly used among the OCs; methyl parathion, monocrotophos, and azinphos ethyl, among the OPs; and carbosulfan among the carbamates. Overall, Filipino farmers prefer OPs to OCs because they are cheaper, widely available and known for wide-spectrum toxicity (Rola and Pingali, 1993). Arce et al. (1984) reported that eighteen rice-fish farmers in Nueva Ecija used insecticides such as carbamates (carbofuran, carbaryl, methomyl, and MIPC), organophosphates (methyl parathion and monocrotophos), and synthetic pyrethroids (cypermethrin and permethrin).

This paper discusses the impacts of pesticides on fish and their implications in the context of fish farming in Philippine ricefields. It presents results of on-station research on fish toxicity, degradation, and residues of selected pesticides in rice-fish culture conducted at the Freshwater Aquaculture Center, Central Luzon State University (FAC-CLSU). Nile tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*) are emphasized because they are highly recommended for culture in rice-fish farming systems.

## 8.2. Pesticide Impact Assessment Methodology

Assessment of pesticide impacts on fish requires some knowledge on their toxicity, persistence, and degradation in a rice-fish farming system. Techniques available to establish these pesticide parameters include laboratory and field experiments. These studies attempt to evaluate the fate and impact of toxicants in ecosystem experiments under natural or simulated environmental conditions. Their holistic approach is expected to provide information required for evaluating the consequences of using pesticides on nontarget aquatic organisms, especially fish.

### 8.2.1. Pesticide Toxicity Tests

Pesticide toxicity can be either acute or chronic. Acute toxicity is the immediate effect of a toxicant manifesting great damage to fish, as in mortality. In places where there is heavy application of pesticide and where fishkills are frequently

Table 8.2. Morphological and Behavioral Changes in Fish Exposed to Sublethal Concentrations of Pesticide

*Morphological changes:*

1. Darkening of skin
2. Formation of brown spot on the forehead
3. Swelling of the eyes
4. Erosion of fin margins
5. Necrosis of maxillary cartilage and fins
6. Darkened areas anterior and posterior to the dorsal fin eventually became deformed
7. Development of hemorrhaged areas anterior and posterior to the dorsal fin
8. Swelling of the abdomen with watery and light yellow liquid in peritoneal cavity
9. Permanently dropped and lower jaws
10. Retardation and regeneration of the caudal fin
11. Erosion of taste buds

*Behavioral changes:*

1. Erratic swimming
2. Marked decline in the frequency of various agonistic behaviors (chasing, vacating, nipping, etc.)
3. Altered station selection with a shift from central position to downstream, near surface, or later positions
4. Fish swim near surface with bloated stomachs and head downward
5. Hypersensitivity to disturbance
6. Impaired swimming ability
7. Avoidance reaction
8. Schooling behavior
9. More rapid expansion and contraction of the buccal and opercular cavities (increased coughing)
10. Apathy to food
11. Reduced feeding on altered feeding behavior
12. Depressed courtship behavior

reported, emphasis is placed on acute toxicity effects on fish (Muirhead-Thomson, 1971). However, the long-term effects of sublethal exposures cannot be underestimated, and these may prove to be the more important aspect of contamination. Some of the morphological and behavioral changes of fish due to sublethal concentrations of pesticides as reported by various authors in Murty (1986) are summarized in Table 8.2. A summary list of biochemical changes in ricefield freshwater warmwater fishes exposed to sublethal concentrations of one carbamate, five organophosphate, and one organochlorine compounds based on various



Table 8.3. Biochemical Changes in Ricefield Freshwater Fishes Exposed to Sublethal Concentrations of Pesticide

| <i>Pesticide</i>        | <i>Fish Species</i>      | <i>Biochemical Changes</i>                                                                                                                                                                                           | <i>Author</i>                                                                |
|-------------------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| <i>Carbamate:</i>       |                          |                                                                                                                                                                                                                      |                                                                              |
| 1. Benthocarb           | <i>Sarotherodon</i> sp.  | Increased ammonia, urea, and glutamine levels in all the tissue                                                                                                                                                      | Seshagiri et al., 1983                                                       |
| <i>Organophosphate:</i> |                          |                                                                                                                                                                                                                      |                                                                              |
| 1. Diazinon             | <i>Channa</i> sp.        | Increased hematocrit values, hemoglobin content, blood glucose, and urea; after 15–30 days of exposure blood cholesterol levels increased                                                                            | Sastry and Sharma, 1981a, 1981b                                              |
| 2. Malathion            | <i>Tilapia</i> sp.       | Increased levels of the amino acids, decreased body sodium, potassium, and calcium levels; altered DNA and RNA content of muscle, liver and gill                                                                     | Kabeer et al., 1984; Kabeer et al., 1981                                     |
|                         | <i>Sarotherodon</i> sp.  | Decreased ammonia and urea levels in tissues                                                                                                                                                                         | Seshagiri et al.                                                             |
|                         | <i>Clarias batrachus</i> | Little alteration of hepatic protein but there was an increase in the free amino acid level with the incorporation of lysine into the protein of liver being drastically produced; marked glycogen and serum glucose | Mukhopadhyay and Dehadrai, 1980                                              |
| 3. Methyl parathion     | <i>Tilapia</i> sp.       | Decreased total lipids and phospholipids while free fatty acids and total cholesterol showed elevated levels in red muscle, gill, liver, and brain; decreased carbohydrates and                                      | Siva et al., 1981; Camp et al., 1974; Kabeer et al., 1981; Siva et al., 1983 |

Table 8.3. (Continued)

| Pesticide       | Fish Species            | Biochemical Changes                                                                                                                                  | Author              |
|-----------------|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
|                 |                         | glycogen of several tissues; decreased body sodium, potassium, and calcium levels                                                                    |                     |
|                 | <i>Sarotherodon</i> sp. | Decreased ammonia and urea levels in tissues                                                                                                         | Siva et al., 1981   |
| 4. Phenthoate   | <i>Channa punctata</i>  | Decreased total protein and increase in free amino acids                                                                                             | Siva et al., 1982   |
| 5. Phosphamidon | <i>Channa punctata</i>  | Increased liver and muscle glycogen content                                                                                                          | Sastry et al., 1982 |
| Organochlorine: |                         |                                                                                                                                                      |                     |
| 1. Endosulfan   | <i>Channa punctata</i>  | Decreased liver lipid content on short term exposure; decreased protein levels; decreased liver and muscle glycogen but increased that of the kidney | Murty et al., 1982  |
|                 | <i>Catfish</i>          | Decreased muscle glycogen                                                                                                                            | Singh et al., 1981  |

Source: As cited by various authors in Murty (1986).

reports in Murty (1986) are also presented in Table 8.3. Chronic toxicity is the long-term effect of small amounts of usually persistent pesticides that could manifest in reduced growth rate and abnormal reproduction in animals. Static (no aeration) bioassay test is commonly employed to establish acute toxicity, while a continuous flow-aeration test is used to establish chronic toxicity.

For the study of pesticide toxicity to fish, the different tests are prioritized in terms of present utility of results as follows: acute toxicity tests first, followed by embryo-larval tests and chronic life cycle tests, histological tests, and physiological and biochemical tests (Murty, 1986).

Acute toxicity tests (short-term bioassay tests) provide estimates of the exposure concentration that is lethal to 50 percent of the test organisms (LC<sub>50</sub>) during a specified period of time, usually forty-eight to ninety-six hours (Mayer and Ellersieck, 1988). For certain organisms, the effective concentration (EC<sub>50</sub>) is calculated based on immobilization, growth, or some identifiable endpoint other

than mortality. The main value of acute test data lies in the provision of a relative starting point for risk assessment, where toxicity of the chemical and its expected environmental concentration, water solubility, and degradation rate are considered. In addition, acute toxicity tests provide a rapid, cost-efficient way to measure comparative toxicity of large numbers of chemicals and chemical formulations as well as estimates of pesticide quantities likely to present hazard to a test organism.

The value of acute toxicity tests however has prompted much debate. Researchers disagree over whether acute or long-term tests are more appropriate because some believe that acute tests greatly underestimate the hazard posed by chemicals that are poorly absorbed, accumulate, or are cumulative in action (Mayer and Ellersieck, 1988).

**8.2.1.1. Laboratory Bioassay Test.** Many pesticide chemicals do not make any demand on dissolved oxygen and for many species of test fish, hence oxygen requirements in static tests are satisfied by natural surface aeration. Artificial aeration of test solution such as in the continuous flow may cause loss of dissolved test materials to the atmosphere (Muirhead-Thomson, 1971). Laboratory bioassay tests at the Freshwater Aquaculture Center, Central Luzon State University (FAC, CLSU) followed the procedures for short-term bioassay test as described in the Standard Methods for the Examination of Water and Wastewater by the American Public Health Association (APHA), American Water Works Association (AWWA), and Water Pollution Control Federation (WCF) (1971, 1974, 1980).

Some modifications were, however, incorporated in the tests. Initial dissolved oxygen (DO) saturation for larger test fish was increased by aerating the tap water before adding the chemical. Test containers used were either glass aquaria or polyethylene bags. Three replicates including a control (no toxicant) were employed for each test concentration. Fish mortality observations were done at twenty-four, forty-eight, and ninety-six hours after application of the test chemical.  $LC_{50}$  was estimated at twenty-four, forty-eight, and ninety-six hours by plotting log of concentration against mortality and finding the concentration level that crosses the 50 percent mortality rate—the reference point where results are relatively more consistent and less variable (Muirhead-Thomson, 1971).

Ranking of pesticide toxicity to fish based on forty - eight-hour  $LC_{50}$  values in ppm of formulated product (f.p.) was as follows: extremely toxic—less than 1.0 ppm, highly toxic—1.0 to 10.0 ppm, moderately toxic—10 to 100 ppm, and least toxic—greater than 100 ppm (Koesoemadinata and Djajadiredja, 1976). Test fishes used included Nile tilapia (*Oreochromis niloticus*) weighing an average of 1.24-13.5 g, Mossambique tilapia (*O. mossambicus*) at 4-14 g, crucian

carp (*Carassius carassius*) at 1.83–14.0g, and common carp (*Cyprinus carpio*) at 4.96 g.

Results of laboratory toxicity studies, however, must be taken with caution when translating to field situations. It should be noted that, while they provide information on possible acute damage to aquatic life in receiving waters,  $LC_{50}$  values do not represent the concentrations that are safe or harmless in aquatic habitats subject to pollution (APHA, AWWA, and WPCF, 1980). Also, acute toxicity does not provide information on the effects of small doses of persistent pesticides that occur for a continued period of time.

Nevertheless, it does not mean that laboratory acute toxicity test results are not useful. Acute-toxicity data can be extrapolated for field use as proposed by some authors. Koesoemadinata (1980) indicated that permissible chemical concentration should be one-tenth of the forty-eight-hour median tolerance limit. Sprague (1970, 1971), meanwhile, reported that pesticide “safe level” is usually derived by multiplying the ninety-six-hour  $LC_{50}$  values by a compound-specific application factor. For example, FAO (1969) suggested an application factor of 0.10 and 0.01 for less persistent pesticides such as organophosphates and carbamates.

**8.2.1.2. Field Toxicity Test.** Rice-fish experiments at FAC, CLSU using 50 to 200 sq m with 5,000 fish/ha stocking density and about 5 to 10 cm paddy water depth were conducted to evaluate the acute toxicity of different insecticides to Nile tilapia and common carp. Mortalities were observed after every insecticide application, twenty-four hours to ninety-six hours thereafter, and extended up to seven to ten days for persistent insecticides. Water used to irrigate the rice-fish paddies came from a pump well and flowed through an open cemented canal to the experimental plots. Fish were either stocked prior to insecticide application or placed six to ten days after the first one. Insecticides were applied from one to four times at rates from within to higher than the recommended. Mortality effects on fish when using pesticides at rates higher than the recommended will show what happens in case a farmer overuses the insecticide. Toxicity of application rates lower than the recommended were also assessed.

In subsequent applications, paddies were either drained to concentrate the fish in the center trench or water was maintained at 10 cm during insecticide application. Dead fish in field toxicity tests can easily be collected after pesticide application but tend to sink after some time and hence pass undetected. This becomes a more difficult situation when rice plants have developed a heavy canopy, thus limiting the field suitability of bioassay tests especially in large areas with thick vegetation. In small unplanted paddies, it is easier to monitor dead fish as there are no rice plants obstructing observation. However, pesticide toxicity may easily diminish with vegetation uptake of pesticide particles.

### 8.2.2. *Pesticide Persistence and Degradation*

Degradation period of pesticides is evaluated by placing a biological indicator like fish in the treated solution. Fish survival defines degradation as a function of time and hence increases as the pesticide slowly degrades through time.

At FAC-CLSU, pesticide degradation tests were conducted either in concrete tanks with soil substrate or in paddies unplanted to rice for one year prior to the test. Pesticide test concentrations used were based on the recommended rates indicated in the product labels.

**8.2.2.1. Tank Degradation Test.** Tank degradation tests consisted of circular cemented tanks measuring 100 cm in diameter and 30 cm high, each filled with 7 cm thick pulverized sun-dried field soil and with about 10 cm deep tap water. They were then conditioned for three to eight days prior to addition of the test chemicals. Degradation tests were carried out in nonshaded or outdoor condition (tanks were exposed to sun) and in shaded or indoor condition (tanks were placed in a well-ventilated building).

**8.2.2.2. Field Degradation Test.** Field degradation tests were done in 2.5 sq m unplanted paddies with 10 cm water depth. Each test concentration was replicated three times, and a control paddy (no insecticide applied) was also provided. Water was tapped from a deep well and flowed through a cemented canal to the paddies. Paddy fields were thoroughly prepared, exposed, and dried under the sun before they were filled up with water. Also dikes between paddies were constructed thick enough to prevent horizontal seepage of water.

Insecticide degradation in both tank and field conditions was evaluated using the biological indicator periodic replacement (BIPR) technique with Nile tilapia (*Oreochromis niloticus*) as test species. The fishes were acclimatized in tanks before the test. Twenty percent of the test species were measured for individual weight and length. Tank degradation tests were stocked with a total of eighty fingerlings per tank (one fingerling per 10 liters), while the field degradation tests were stocked with fifty fingerlings per paddy. Fish stocking was done by batch. The first batch was stocked to each tank or paddy immediately after applying the insecticide test concentration and for every twenty-four hours thereafter. A new batch of fish was repeatedly stocked to avoid gain of resistance for the survivors. If more than 50 percent survived after twenty-four hours, the observation was extended up to forty-eight hours before stocking a new batch of fish. The process was repeated until insecticide toxicity (as indicated by fish mortality) diminished. Monitoring of fish mortality was done every twenty-four hours until two successive 100 percent survival rates were achieved. Toxicity

was assumed to be gone when zero fish mortality rate was obtained, such that the relevant degradation period is at the second 100 percent survival observed.

### 8.2.3. *Pesticide Residue Analysis*

Residue levels in water and in whole live and dead fish (Nile tilapia) from unplanted paddies of the field degradation tests and planted rice-fish paddies of the field toxicity trials were determined employing gas chromatography standard procedures. Fish mortality was also observed along with residue analysis. Fish samples were collected before and after insecticide application, and the least detectable insecticide concentration was indicated. The gas chromatograph apparatus used was a Tracor Model 540 equipped with flame photometric detector unit at the National Postharvest Institute for Research and Extension (NAPHIRE) at CLSU. Lastly, residue levels in fish was assessed against the FAO/WHO-prescribed allowable daily intake (ADI) (ARSAP/CIRAD, 1988).

## 8.3. Results and Discussion

### 8.3.1. *Pesticide Toxicity to Fish*

Measuring  $LC_{50}$  as the parameter of acute toxicity is a routine procedure to rank pesticides in the order of their fish toxicity and provide estimates of levels likely to present hazard to fish in extreme condition. Pesticides were ranked as follows: extremely toxic—less than 1.0 ppm, highly toxic—1.0 to 10.0 ppm, moderately toxic—10 to 100 ppm, and least toxic—greater than 100 ppm (Koesoemadinata and Djajadiredja, 1976).

**8.3.1.1. Insecticides.** Table 8.4 presents the forty-eight- and ninety-six-hour acute toxicity on fish of some insecticides commonly used in Laguna and Nueva Ecija, Philippines. The median lethal concentrations ( $LC_{50}$ ) obtained indicated possible mortality when fish is directly exposed to the pesticide in the natural environment. Acute toxicities based on forty-eight-hour  $LC_{50}$  (ppm of f.p.) of most insecticides tested ranged from extremely toxic (1 to 10 ppm) to moderately toxic (10 to 100 ppm). Interestingly though, none of the insecticides tested exhibited low toxicity to both tilapia and crucian carp (Table 8.4a).

Results showed that one insecticide can belong to more than one toxicity category depending on the test fish species, as in the case of monocrotophos, permethrin and BPMC. Based on the forty-eight-hour  $LC_{50}$ , permethrin was extremely toxic to *O. niloticus* but highly toxic to *O. mossambicus*. Monocrotophos

Table 8.4. Acute Toxicity of Various Pesticides Used by Rice Farmers of Nueva Ecija and Laguna, Philippines Tested at the Freshwater Aquaculture Center, Central Luzon State University, Philippines

| Pesticide            | <i>LC<sub>50</sub> (ppm of formulated product)</i> |           |                            |       |                     |       |
|----------------------|----------------------------------------------------|-----------|----------------------------|-------|---------------------|-------|
|                      | <i>Nile Tilapia</i>                                |           | <i>Mossambique tilapia</i> |       | <i>Crucian carp</i> |       |
|                      | 48-hr                                              | 96-hr     | 48-hr                      | 96-hr | 48-hr               | 96-hr |
| Carbamate:           |                                                    |           |                            |       |                     |       |
| BPMC                 | 5.60–6.70                                          | 5.40–6.12 | -                          | -     | 28.30               | 25.20 |
| Carbaryl             | 3.10                                               | 2.93      | -                          | -     | -                   | -     |
| Carbofuran           | 2.27                                               | 1.97      | 2.40                       | 1.72  | -                   | -     |
| MTMC                 | 68.00                                              | 50.00     | 52.00                      | 46.90 | -                   | -     |
| MTMC + phenthoate    | 0.56                                               | 0.47      | -                          | -     | -                   | -     |
| MIPC                 | 59.00                                              | 47.10     | -                          | -     | 34.80               | 19.60 |
| Organophosphate:     |                                                    |           |                            |       |                     |       |
| Azinphos-ethyl       | 0.028                                              | -         | -                          | -     | 0.009               | 0.002 |
| Chlorpyrite          | 2.00                                               | 1.30      | 1.34                       | 1.19  | -                   | -     |
| Diazinon             | 45.00                                              | 2.20      | -                          | -     | 40.70               | 15.20 |
| Methyl parathion     | 25.70                                              | 19.00     | -                          | -     | 13.40               | 11.00 |
| Monocrotophos        | 1.20                                               | -         | 47.60                      | 33.10 | 0.31                | -     |
| Triazophos           | 5.60                                               | -         | -                          | -     | -                   | -     |
| Organochlorine:      |                                                    |           |                            |       |                     |       |
| Endosulfan           | 5.80                                               | 1.30      | -                          | -     | 1.30                | 1.60  |
| Synthetic Pyrethoid: |                                                    |           |                            |       |                     |       |
| Permethrin           | 0.75                                               | 0.75      | 1.30                       | -     | -                   | -     |
| Cypermethrin         | 0.63                                               | 0.63      | -                          | -     | -                   | -     |

Sources: Dela Cruz and Cagauan (1981); various authors cited in Cagauan and Arce (1992).

was extremely toxic to *C. carassius*, highly toxic to *O. niloticus*, and moderately toxic to *O. mossambicus*. BPMC was highly toxic to *O. niloticus* and moderately toxic to *C. carassius*. MTMC (50 percent ai) was moderately toxic to *O. niloticus* and *O. mossambicus* but became extremely toxic to *O. niloticus* when mixed with phenthoate (MTMC + phenthoate; 6 percent ai).

Carbofuran was highly toxic and MTMC was moderately toxic to the two tilapia species. PMP, diazinon and methyl parathion were moderately toxic and endosulfan was highly toxic to *O. niloticus* and *C. carassius*.

From these results, insecticide toxicity can be ranked as follows: synthetic pyrethroids > organophosphates > carbamates. The organochlorine (OC) group cannot be ranked, as there was only one such insecticide (endosulfan) tested.

Table 8.4a. Summary of Insecticide Toxicity on Selected Fish Species Based on Forty-Eight-Hour LC<sub>50</sub>

| <i>Toxicity Level</i>                 | <i>Nile tilapia<br/>(Oreochromis niloticus)</i>                                             | <i>Fish Species<br/>Mossambique tilapia<br/>(O. mossambicus)</i> | <i>Crucian Carp<br/>(Carassius carassius)</i> |
|---------------------------------------|---------------------------------------------------------------------------------------------|------------------------------------------------------------------|-----------------------------------------------|
| Extremely toxic<br>(< 1 ppm f.p.)     | MTMC + phenthoate<br>Cypermethrin<br>Permethrin                                             |                                                                  | Azinphos-ethyl<br>Monocrotophos               |
| Highly toxic<br>(1–10 ppm)            | BPMC<br>Carbaryl<br>Carbofuran<br>Chlorpyrites<br>Monocrotophos<br>Triazophos<br>Endosulfan | Carbofuran<br>Chlorpyrite<br>Permethrin                          | Endosulfan                                    |
| Moderately toxic<br>(10–100 ppm f.p.) | MTMC<br>Methyl parathion<br>Diazinon<br>MIPC                                                | MTMC<br>Monocrotophos                                            | BPMC<br>Diazinon<br>Methyl parathion<br>PMP   |



Endosulfan was found highly toxic to both *O. niloticus* and *C. carassius*. In general, OC compounds are more toxic to fish than OP compounds, although a few of the latter are as toxic as some of the highly toxic OC compounds (Murty, 1986).

Macek and McAllister (1970) and Koesoemadinata (1975) reported that carbamates are less toxic than organochlorines and organophosphates. Holden (1972) reported that many more organochlorine pesticides are toxic to fish than organophosphates, although the reverse is true for zooplanktons and some insect larvae. Koesoemadinata (1975) also showed that carbamates and organophosphates are less toxic to common carp (*Cyprinus carpio*) than organochlorines.

In general, OC compounds are more toxic to fish than OP compounds although a few of the latter are as toxic as some of the highly toxic OC compounds (Murty, 1986). Also, while the acute toxicity of synthetic pyrethroids to fish is high, they are not as persistent in the environment (Coats and O'Donnell-Jeffery, 1979 as cited in Leahey, 1985) and have low mammalian toxicity (Magallona, 1980).

Sensitive fish species are those whose mortality or survival rates are influenced with small amounts of the insecticide; tolerant ones are those affected with large amounts. Based on the forty-eight-hour  $LC_{50}$  (Table 8.4), for example, *O. mossambicus* was more tolerant than *O. niloticus* to carbofuran, while *O. niloticus* was more tolerant than *C. carassius* to diazinon, methyl parathion, and monocrotophos. When both test species belong to one toxicity category, the one with a lower forty-eight-hour  $LC_{50}$  is more sensitive. Hence, fish sensitivity information can indicate the pollution potential or quality of a pesticide. In general, fish sensitivity to pesticides is affected by species, size, and age and also by environmental abiotic factors such as water hardness and pH (Koesoemadinata, 1980).

Results of the laboratory bioassay tests provide a good example of how standard fish toxicity tests may be used to forecast the likely impact of pesticide dosage in terms of kg active ingredient (ai) per hectare. Median lethal concentrations ( $LC_{50}$ ) at forty-eight- and ninety-six-hour were computed to obtain one-hectare 5-cm water deep field application rates (totalling approximately 500,000 liters). For a normal rice-fish farm, 10 percent of the ricefield area is allotted as fish refuge. Extrapolation of the  $LC_{50}$  to field application rates however is based on a normal ricefield area for rice monoculture.

Table 8.5 compares the insecticide median lethal concentrations ( $LC_{50}$ ) obtained in the laboratory against the recommended application rates in kg ai/ha. It can be noted that the insecticide recommended rates are much higher compared to the safe concentration levels<sup>2</sup> obtained. These could readily result in fish mortality on application. Field evaluation of insecticide toxicity to Nile tilapia, for example, shows that MTMC + phenthoate, carbaryl, MIPC, monocrotophos,

and triazophos resulted in mortality after the second application. Fish mortality, meanwhile, was detected after the second to the fourth application of carbofuran.

Several experiments at FAC-CLSU demonstrated that, before fish stocking, the first application of carbamates, organophosphates, or synthetic pyrethroids using recommended rates and rates lower or higher than the recommended did not produce any fish mortality even after six to ten days. This indicated that insecticide toxicity had already dissipated by the time the fish were stocked. However, pesticide applications after fish stocking resulted in mortalities.

In some experiments where paddies were drained to concentrate the fish in the trench prior to application, subsequent applications also resulted in fish mortality. This, meanwhile, can be attributed to insecticide drift in the water during spraying. Moreover, the trench was not deep enough for fish to take refuge during application. It is commonly observed that 0.75 cm deep, 1 m wide trenches in rice-fish farms become shallow due to erosion as rice culture progresses. As an alternative, a pond refuge of 1 m water depth may serve as a better buffer zone during pesticide application.

Subsequent applications that did not produce fish mortality were those using one carbamate and two synthetic pyrethroids. These were MTMC + phenthoate at 0.26 kg ai/ha, permethrin at 0.05 to 0.125 kg ai/ha, and cypermethrin at 0.025 to 0.05 kg ai/ha. The rate used for MTMC + phenthoate is more than half of the minimum recommended rate and higher than the safe concentration level. Interestingly, the range of permethrin rates that were not detrimental to paddy fish were higher than both the recommended and safe concentration levels. Fish mortality was observed at 0.25 to 0.50 kg ai/ha of permethrin and at 0.125 to 0.25 kg ai/ha of cypermethrin.

In general, fish are at risk when directly exposed to the insecticide using recommended rates applied by broadcasting or spraying. Overdosing (using higher than the maximum recommended rate), except for some rates of synthetic pyrethroids, is more fatal to the fish. Underdosing to about one-third of the minimum recommended rate, as in the case of MTMC + phenthoate, did not cause any fish mortality. An increase of about 1.5 to four times the maximum recommended rate of permethrin (0.03 kg ai/ha) but not higher was safe for the fish. Mortality was not observed at cypermethrin rates of about 0.5 to 1.5 times the maximum recommended rate of 0.03 kg ai/ha, but was apparent at rates four times or higher of the same.

Interestingly, the lethal concentrations of permethrin (0.0315 kg ai/ha) and cypermethrin (0.0375–0.065 kg ai/ha) obtained in the laboratory bioassay tests did not produce fish mortality in the field. This observation reflects the rapid adsorption in abiotic and biotic surfaces including fish, and degradation in the natural environment. Adsorbed pyrethroid pesticides in fish are also rapidly metabolized as in the case of carbamates and OPs but not of OCs (Murty, 1986).

Table 8.5. Field Toxicity Trials of Insecticides on Nile tilapia (*Oreochromis niloticus*) in Controlled Rice-Fish Experiments

| Insecticide<br>Formulation<br>(% ai) | Median Lethal<br>Concentration<br>(LC <sub>50</sub> )<br>(kg ai/ha) | Recommended<br>Application Rate |      | Application<br>Rate in the<br>Experiment<br>(kg ai/ha) | Number of Application<br>and Fish Effect<br>(+ = fish mortality)<br>(- = no fish mortality) |   |   |   | Fish<br>Mortality<br>(%) |
|--------------------------------------|---------------------------------------------------------------------|---------------------------------|------|--------------------------------------------------------|---------------------------------------------------------------------------------------------|---|---|---|--------------------------|
|                                      |                                                                     | Min.                            | Max  |                                                        |                                                                                             |   |   |   |                          |
|                                      |                                                                     | (kg ai/ha)                      |      |                                                        | 1                                                                                           | 2 | 3 | 4 |                          |
| MTMC + phenthoate<br>(G/6)           | 0.0168                                                              | 1.02                            | 2.04 | 1.02                                                   | Broadcast                                                                                   | - | + |   | 6.67                     |
|                                      |                                                                     |                                 |      | 0.51                                                   | Broadcast                                                                                   | - | + |   | 0.67                     |
|                                      |                                                                     |                                 |      | 0.26                                                   | Broadcast                                                                                   | - | - |   | 0                        |
| BPMC<br>(EC/50)                      | 1.4–7.08                                                            | 0.50                            | 0.75 | 0.75                                                   | Sprayed                                                                                     | + |   |   | 0.67                     |
|                                      |                                                                     |                                 |      | 1.00                                                   | Sprayed                                                                                     | + |   |   | 1.33                     |
|                                      |                                                                     |                                 |      | 2.13                                                   | Sprayed                                                                                     | - | + |   | a                        |
| Carbaryl<br>(WP/85)                  | 0.034–0.036                                                         | 0.50                            | 1.00 | 1.00                                                   | Broadcast                                                                                   | - |   |   | 0                        |
|                                      |                                                                     |                                 |      | 1.00                                                   | Broadcast                                                                                   | - | + | + | +100                     |
|                                      |                                                                     |                                 |      | 1.00                                                   | Rootzone<br>injection                                                                       | - |   |   | 0                        |
| MIPC<br>(WP/50)                      | 8.7–17.25                                                           | 0.25                            | 0.50 | 2.00                                                   | Rootzone<br>injection                                                                       | - |   |   | 0                        |
|                                      |                                                                     |                                 |      | 1.00                                                   | Sprayed                                                                                     | - | + |   | a                        |
|                                      |                                                                     |                                 |      | 0.43                                                   | Sprayed                                                                                     | - | + |   | a                        |
| Monocrotophos<br>(EC/28.5)           | 0.171–6.78                                                          | 0.25                            | 0.50 | 0.63                                                   | Sprayed                                                                                     | - |   |   | a                        |
|                                      |                                                                     |                                 |      | 0.35                                                   | Sprayed                                                                                     | - | + |   | a                        |
| Chlorpyrifate<br>(EC/31.5)           | 0.211–0.315                                                         | 0.25                            | 0.35 | 0.63                                                   | Sprayed                                                                                     | - | + |   | a                        |
| Azinphos-ethyl<br>(EC/40)            | 0.0018                                                              | 0.40                            | 0.60 | 0.40                                                   | Sprayed                                                                                     | + |   |   | 79.67                    |

|                             |              |      |      |      |         |   |   |       |
|-----------------------------|--------------|------|------|------|---------|---|---|-------|
| Methyl parathion<br>(EC/50) | 3.35–6.425   | 0.50 | 0.75 | 0.50 | Sprayed | + |   | 2.33  |
| Triazophos<br>(EC/40)       | 1.12         | 0.25 | 0.40 | 0.60 | Sprayed | - | + | 53.39 |
| Permethrin<br>(EC/10)       | 0.0315       | ?    | ?    | 0.05 | Sprayed | - | - | 0     |
|                             |              |      |      | 0.10 | Sprayed | - | - | 0     |
|                             |              |      |      | 0.13 | Sprayed | + | + | a     |
|                             |              |      |      | 0.25 | Sprayed | + | + | a     |
|                             |              |      |      | 0.50 | Sprayed | + | + |       |
| Cypermethrin<br>(EC/10)     | 0.0375–0.065 | ?    | ?    | 0.03 | Sprayed | - | - | 0     |
|                             |              |      |      | 0.05 | Sprayed | - | - | 0     |
|                             |              |      |      | 0.05 | Sprayed | - | - | 0     |
|                             |              |      |      | 0.13 | Sprayed | + | + | a     |
|                             |              |      |      | 0.25 | Sprayed | + | + | a     |

a. Fish mortality observed resulting to low fish yield.

At this point, it should be noted that the application factor of 1/10 of the forty-eight-hour  $LC_{50}$  considered safe to the fish does not hold true for BPMC, MPC, monocrotophos, and methyl parathion. In these cases, the application factor to be used should be 1/100.

The conventional methods of insecticide application such as broadcasting for granular forms and spraying for emulsifiable concentrates (EC) and wettable powders (WP) are considered detrimental to fish as they directly expose the fish to the chemical compound. Granular formulation also has some advantages over sprays. These include better location, the reduction of drift to adjacent areas, and the avoidance of excessive concentrations at the time of application or shortly afterward (Koeman, 1974, as cited in Koesoemadinata, 1980). The danger of runoff or leaching of pesticides depends on their water solubility and the rate of application (Koesoemadinata, 1980). Hence, pesticides that are generally mobile in irrigated rice fields are those that are highly soluble. In an attempt to maximize insecticide efficiency by lengthening the residual period and thus decreasing the number of insecticide applications, the root zone concept of application was developed (Heinrichs et al., 1977). Such application procedure may not pose mortality risks to fish even at higher rates of the insecticide since direct exposure of fish to the chemical is minimized. This then may prove compatible with fish culture. However, as Seiber (1977) gathered, undesirable insecticide residues can possibly contaminate the harvested fish as in the case of carbofuran.

**8.3.1.2. Biological and Botanical Insecticides.** Recently, a move was initiated to promote biological and botanical insecticides as an alternative to chemical-based compounds, which have generated serious concerns in relation to food safety. Biological pesticides or biopesticide applications are preparations or formulations manufactured for use in controlling or eradicating diseases, insect pests, or weeds. Their active ingredient or basic principle is based on living microorganisms and is derived without significant purification or modification from one of the following: bacterium, fungus, virus, nematode, and protozoans. Biopesticides share only less than 1 percent of the chemical crop protection market (Lizansky, 1993). The major biopesticides are *Bacillus thuringiensis* (BT), an aerobic gram-positive spore-forming bacterium, and nuclear polyhedrosis virus (NPV). Biological insecticides appear very promising as components of integrated pest control (IPC) (Magallona, 1980). The effect of biopesticides to fish is unknown. Botanical insecticides come from plants that possess insecticidal properties such as the neem tree (*Azadirachta indica*), “lagundi” (*Vitex negundo*), “sambong” (*Blumea balsamifera*), “makabuhay” (*Tinospora rumphii*), and oregano (*Coleus amboinicus*).

Fish toxicities of these botanical insecticides are presented in Table 8.6. Based on the twenty-four-hour  $LC_{50}$ , neem was the most toxic to Nile tilapia

Table 8.6. Acute Toxicity (LC<sub>50</sub>) of Four Botanical Plants on Nile Tilapia (*Oreochromis niloticus*)<sup>a</sup> and Common Carp (*Cyprinus carpio*)<sup>a</sup>

| Botanical Plant: Common<br>Name, Scientific Name, and<br>Part of Plant Used |              | LC <sub>50</sub> (g/L) |       |       |
|-----------------------------------------------------------------------------|--------------|------------------------|-------|-------|
|                                                                             |              | 24-hr                  | 48-hr | 96-hr |
| 1. "Sambong"<br>( <i>Blumea balsamifera</i> )<br>Leaves                     | Nile tilapia | 4.98                   | 3.21  | 1.54  |
|                                                                             | Common carp  | 1.60                   | 1.37  | 1.37  |
| 2. "Lagundi"<br>( <i>Vitex negundo</i> )<br>Leaves                          | Nile tilapia | MF <sup>b</sup>        | MF    | 4.95  |
|                                                                             | Common carp  | MF                     | 5.61  | 3.53  |
| 3. Neem tree<br>( <i>Azadirachta indica</i> )<br>Seeds                      | Nile tilapia | MF                     | 5.28  | 1.59  |
|                                                                             | Common carp  | 4.17                   | 1.17  | 0.55  |
| 4. "Makabuhay"<br>( <i>Tinospora rumphii</i> )<br>Stems                     | Nile tilapia | MF                     | 4.94  | 0.77  |
|                                                                             | Common carp  | 5.97                   | 4.90  | 2.13  |

Source: Leano and Cagauan (1992).

a. Average body weight = 0.8-1.5 g.

b. MF = mortality rate below 50 percent.

while "sambong" and "makabuhay" were toxic to common carp. At ninety-six hours of exposure, "sambong" and "makabuhay" were the most toxic to Nile tilapia, "sambong" to common carp, and "lagundi" to both fish species (Leano and Cagauan, 1992).

Botanical insecticides can also be used as a management tool to eradicate unwanted fishes in fish ponds, hence used as a piscicide. Cagauan (1984) lists some of the plant-derived insecticides that may be used as fish toxicant. Tumanda (1980) found that the application of 10 ppm powder form derris roots (*Derris elliptica*) to brackishwater ponds was effective for controlling 14 fish species. For one, derris root powder can be effective in controlling *Poecilia reticulata* at 5 ppm in freshwater and at 10 to 30 ppm in brackishwater (Guerrero, Guerrero, and Garcia, 1989). With such piscicidal properties, botanical insecticides, although less effective than chemical insecticides because of photo-lableness, can contaminate ricefields and paddy fish through the irrigation water.

**8.3.13. Herbicides.** Herbicide use has been increasing in Philippine irrigated rice areas, both in terms of the number of farmers and of frequency of application. In Nueva Ecija, number of herbicide application in the dry season increased from one in the 1970s to two in the 1980s. In Laguna, wet season herbicide application increased from once in the 1960s to twice in the 1970s and 1980s.

Table 8.7. Toxicity of Herbicide to Nile tilapia (*O. niloticus*), Crucian Carp (*Carassius carassius*), and Common Carp (*Cyprinus carpio*)

| Herbicide                  | Fish Species                 | LC <sub>50</sub> (ppm f.p.) |          |       |
|----------------------------|------------------------------|-----------------------------|----------|-------|
|                            |                              | 24-hr                       | 48-hr    | 96-hr |
| A. Phenoxy-aliphatic acids |                              |                             |          |       |
| 1. MCPA                    | <i>Cyprinus carpio</i>       | 520.0                       | —        | —     |
|                            | <i>Macrobrachium</i> sp.     | 1840.0                      | —        | —     |
|                            | <i>Corbicula manilensis</i>  | 4600.0                      | —        | —     |
| 2. 2,4-D amine             | <i>C. carpio</i>             | 800.0                       | —        | —     |
|                            | <i>Macrobrachium</i> sp.     | 920.0                       | —        | —     |
|                            | <i>C. manilensis</i>         | 5300.0                      | —        | —     |
| 3. 2,4-D + piperophos      | <i>Oreochromis niloticus</i> | 67.5                        | 63.5 MT  | 54.5  |
| B. Substituted amines      |                              |                             |          |       |
| 1. Butachlor               | <i>O. niloticus</i>          | 1.4                         | 1.4 HT   | 1.3   |
| 2. Trifluralin             | <i>O. niloticus</i>          | 103.0                       | 71.5 MT  | 54.4  |
|                            | <i>Carassius carassius</i>   | 76.0                        | 53.5 MT  | 49.5  |
| 3. Bifenox                 | <i>O. niloticus</i>          | 187.50                      | 149.0 LT | 127.0 |
|                            | <i>C. carassius</i>          | 170.0                       | 128.0 LT | 102.0 |
| 4. EPTC                    | <i>O. niloticus</i>          | 395.0                       | 308.0 LT | 225.0 |
|                            | <i>C. carassius</i>          | 342.0                       | 190.0 LT | 170.0 |

Sources: Dela Cruz and Cagauan (1981); Santiago and Recometa (1981).

Note: HT = highly toxic (1–10ppm), MT = moderately toxic (10–100ppm), and LT = low toxic (> 100 ppm).

Average dosage however has remained relatively constant for both Laguna and Nueva Ecija, and there has been a significant shift from more hazardous to less hazardous herbicides in the same. Laguna rice farmers commonly used 2,4-D and butachlor, while Nueva Ecija farmers used mostly 2,4-D + piperophos, 2,4-D + thiobencarb, butachlor, pretilachlor, and thiobencarb (Chapter 3).

While insecticide use was found to have low yield effects (Rola and Pingali, 1993), herbicide use has definite positive effects on rice yield. The question now lies in the possible impacts of herbicides on fish, which this paper attempts to address in the following discussion.

Table 8.7 shows the acute toxicity of different herbicides to fish and other aquatic organisms. Based on the forty-eight-hour LC<sub>50</sub>, no herbicide tested as extremely toxic to fish. Butachlor however tested as the only herbicide highly toxic to *O. niloticus*. Trifluralin and 2,4-D + piperophos were moderately toxic while bifenox and EPTC had low toxicity to *O. niloticus* and *C. carassius*. At

Table 8.8. Herbicide Recommended Field Application Rate Compared to the Twenty-Four-Hour Median Lethal Concentration (LC<sub>50</sub>) Expressed as kg Active Ingredients (ai) per ha

| Herbicide          | Formulation (% ai) | Recommended     |                                   | Fish Species        |
|--------------------|--------------------|-----------------|-----------------------------------|---------------------|
|                    |                    | Rate (kg ai/ha) | 24-hr LC <sub>50</sub> (kg ai/ha) |                     |
| Butachlor          | EC (60)            | 1.0             | 0.42                              | <i>O. niloticus</i> |
| 2,4-D + piperophos | EC (50)            | 0.26-1.5        | 16.88                             | <i>O. niloticus</i> |
| MCPA               | EC (40.5)          | 0.12-0.46       | 105.3                             | <i>C. carpio</i>    |
| 2,4-D amine        | G (3.0)            | 0.60            | 12.0                              | <i>C. carpio</i>    |

Table 8.9 Median Tolerance Limits (TL<sub>m</sub>) of Common Carp (*Cyprinus carpio*) to Herbicides

| Herbicide                  | 48-hr TL <sub>m</sub> (ppm) | Toxicity Category |
|----------------------------|-----------------------------|-------------------|
| 2,4-D                      | > 40.0                      | Moderately toxic  |
| DMNP                       | 14.0                        | Moderately toxic  |
| Propanil                   | 0.42                        | Extremely toxic   |
| Nitrofen                   | 2.10                        | Highly toxic      |
| Benthiocarb                | 3.6                         | Highly toxic      |
| Amine methan - earrsonates | 3.72                        | Highly toxic      |
| GS 13633                   | 0.86                        | Extremely toxic   |
| Hedazhuang                 | 34.0                        | Moderately toxic  |
| Oradiazon                  | 3.2                         | Highly toxic      |
| Prometryne                 | 23.5                        | Moderately toxic  |
| Glyphosate                 | 119.0                       | Low toxic         |
| Pentachlorophenol          | 0.35                        | Extremely toxic   |

Source: Liu, 1986, as cited in Xiao (1992).

twenty-four hours after introducing common carp (*Cyprinus carpio*), 50 percent of the test animals died at 520 and 800 ppm f.p. of MCPA and 2,4-D amine respectively. Table 8.8, in turn, shows that the recommended field application rates of 2,4-D amine, 2,4-D + piperophos and MCPA are lower than the LC<sub>50</sub> values. This indicates that the field rates may not manifest direct toxicity to the test fishes. The recommended rate of butachlor however is higher than the LC<sub>50</sub> and thus can lead to fish mortality in the field.

In China, the median tolerance limits (TL<sub>m</sub>) of *Cyprinus carpio* to various herbicides are shown in Table 8.9. TL<sub>m</sub>, also known as TL<sub>50</sub>, indicates the concentration at which at least 50 percent of the test animals can survive. This expression is similar to LC<sub>50</sub> but differs in emphasis. TL<sub>50</sub> emphasizes the



concentration at which 50 percent of the test animals survived while  $LC_{50}$  emphasizes the concentration at which 50 percent of the animals died. For this reason, the  $TL_{50}$  values in Table 8.9 can be treated as  $LC_{50}$  values.

Based on the toxicity ranking adapted from Koesoemadinata and Djajadiredja (1976), Table 8.9 lists three extremely toxic herbicides, four highly toxic, four moderately toxic, and one herbicide with low toxicity. Due to unavailability of data, however, it cannot be discerned if the various forty-eight-hour  $TL_{ms}$  of herbicides on *C. carpio* are below or above the recommended field application rates (Liu, 1986, as cited in Xiao, 1992).

In the field, treatment of ponds with 1 ppm diquat had no adverse effect on fish although the nuisance weeds in question (*Elodea canadensis*) all died and decomposed within a week after treatment. In 1966, Hilsenhoff reported that diquat was an effective weed control at 1 to 3 ppm, which is a much lower rate than the levels detrimental to fish.

Few herbicides have any chronic toxicity to fish (Murty, 1986), and most have low acute toxicity to fish (Murty, 1986; Muirhead-Thomson, 1971; Khan, 1977). The toxicity of many herbicides to plants as against the aquatic animals is less by several orders of magnitude (Kenaga and Moolenaar, 1979; Frank, 1972, as cited in Murty, 1986). Hydrogen ion concentration (pH) influences the toxicity of herbicides, as most of them are ionizable (Murty, 1986). The unionized state of the compound has greater toxicity than the dissociated components, and the degree of ionization is dependent on pH. Although herbicides have much less toxicity to fish and invertebrates than insecticides, relatively high concentration of the former are thus needed for effective weed control. Highly toxic preemergent herbicides, which are usually applied before fish stocking within the first week of rice transplanting, may not present any risk for fish as their toxicity may have already dissipated by the time of fish stocking. However, highly toxic postemergent herbicides usually applied fourteen days after transplanting and fish stocking may cause acute toxicity to fish that may in turn result in massive mortality. Phytoplanktons, the natural primary food of Nile tilapia, a macrophytophagous fish species, could be adversely affected by herbicide application for sometime, but successive phytoplankton population after application could be higher than the first (see Chapter 6 for pesticide effects on planktons). As most herbicides have low acute toxicity to fish, the major problem arises not from its direct toxicity due to application but from the resulting decomposition of weeds that deteriorate dissolved oxygen (DO) levels in the water (Murty, 1986).

**8.3.1.4. Molluscicides.** In the Philippines, molluscicide application in ricefields increased after *Pomacea* sp., a herbivorous snail, was introduced and popularized in 1980 (Juliano, Guerro, and Ronquillo, 1989) and 1982 (Mochida, 1987)

as a cheap source of human food, but eventually became a major rice pest. Escalada (1989) reported that snail infestation can cause a yield loss of as much as 40 percent. Chemical control of these snails before rice transplanting was found effective (Basilio, 1989), but organotin compounds such as fentin chloride and fentin acetate were reported to have adverse effects on humans like itchiness, bruises and cuts, delayed healing of wounds, and nail discoloration and distortion (Adalla and Morallo-Rejesus, 1989; Cheng, 1989; Escalada, 1989). Tin-based compounds have dangerous environmental effects, as have been experienced in cage aquaculture with tin-based antifoulants (Acosta and Pullin, 1991). For these reasons, these organotin compounds were banned in the Philippines in 1990 (Cagauan and Arce, 1992).

Molluscicides are commonly applied to control aquatic snail species that are intermediate hosts in human bilharziasis (Muirhead-Thomson, 1971). Niclosamide was one of first molluscicides developed for bilharziasis control but was, however, toxic to fish. Despite of this, it gained popularity in many countries as a molluscicide, particularly where bilharziasis control is the overriding consideration and where no serious conflict with fish culture is present (Muirhead-Thomson, 1971). Because of its toxicity to fish, niclosamide is used to control undesirable fish populations; proved highly toxic to eighteen species of freshwater fish, including catfish, which is resistant to other chemicals (Marking and Hogan, 1967, as cited in Muirhead-Thomson, 1971). The authors also found niclosamide toxic to fish even in very brief exposure and does not become proportionately more toxic with increased exposure. Harrison (1966) further found niclosamide more toxic to fish in soft water than in hard water.

Table 8.10 presents the summary of effects of early molluscicide application including niclosamide to fish. They were mostly applied to open waters such as dams, canals, and fish ponds in view of primarily eradicating the snail host of bilharziasis. Such open-water condition is different from ricefields. The latter's shallow depth and increased water temperature contributes to better molluscicide effectivity. In general, molluscicide activity is increased at higher temperatures, and snail metabolism is reduced in lower temperatures (Muirhead-Thomson, 1971).

Some molluscicides marketed in the Philippines and their recommended application rates are presented in Table 8.11. One containing niclosamine, methylisobutyl ketone, and isobutanol is applied at 0.58 to 0.82 kg ai/ha in 3 to 5 cm water. It is commonly applied after rice transplanting and the field has not been irrigated for forty-eight hours.

Another molluscicide commonly used by Filipino rice farmers is metaldehyde (WP 75 percent), whose recommended application rate is 0.7875 kg ai/ha. It has a toxic effect on the snails' nervous system (Mills, Bailey, McCrohan, and Wedgwood, 1989) and possesses anaesthetic properties (Mills, Bailey, McCrohan

Table 8.10. Summary of Effects of Some Molluscicides in Fish

| <i>Molluscicide</i>                 | <i>Concentrated<br/>Treatment<br/>(in ppm)</i> | <i>Condition<br/>Applied</i> | <i>Fish<br/>Species</i>                 | <i>Effect</i>                                                                | <i>Authors</i>                        |
|-------------------------------------|------------------------------------------------|------------------------------|-----------------------------------------|------------------------------------------------------------------------------|---------------------------------------|
| Niclosamide<br>(wettable<br>powder) | 0.3-1.5                                        | -                            | <i>Lebistes</i>                         | Toxic to fish as it was for<br>snails for 24 hours                           | Muirhead-Thomson, 1971                |
|                                     | Normal<br>snail control                        | field                        | Various species<br>including<br>tilapia | Toxic                                                                        | Muirhead-Thomson, 1971                |
|                                     | 1.6                                            | -                            | <i>Poecilia<br/>januarensis</i>         | Died within 2 hours                                                          | Paulini, Chaia and<br>deFnetas, 1961  |
|                                     | 0.4                                            | -                            | <i>Poecilia<br/>januarensis</i>         | 96% survived after 48 hrs                                                    | Paulini, Chaia and<br>deFrietas, 1961 |
|                                     | 0.10                                           | Soft water                   | <i>Barbus<br/>trimaculatus</i>          | Died within 5-10 minutes                                                     | Harrison, 1966                        |
|                                     | 0.20                                           | Hard<br>water                | <i>Barbus<br/>trimaculatus</i>          | Fishkill much slower; no<br>fish mortality occurred until<br>after two hours | Harrison, 1966                        |
| N-tritylmor-<br>pholine             | 0.25                                           | Dams                         | <i>Barbus</i> sp.<br><i>Clarias</i> sp. | Death                                                                        | Shiff, 1966                           |
|                                     | 0.25                                           | Irrigation<br>canals         | Large number<br>of fishes               | Death                                                                        | Shiff, 1966                           |
|                                     | 0.10                                           | canals                       | <i>Barbus</i> sp.<br><i>Tilapia</i> sp. | Death within 6 hours                                                         | Boyce, Crossland and<br>Shiff, 1966   |

|                  |                                   |                            |                                                                                                                                                                                    |                                                                                 |                                  |
|------------------|-----------------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|----------------------------------|
| Cuprous oxide    | 0.04                              | Flowing water              | <i>Tilapia mossambica</i> =<br><i>Oreochromis mossambicus</i><br><i>Tilapia melanopleura</i><br><i>Barbus</i> sp.<br><i>Tilapia</i> sp.<br><i>Barbus</i> sp.<br><i>Tilapia</i> sp. | Survived 7 days exposure                                                        | Shiff and deClarke, 1967         |
|                  | 0.10                              | canals                     |                                                                                                                                                                                    | 63% died                                                                        | Shiff and deClarke, 1967         |
|                  | 0.025                             | Canals                     |                                                                                                                                                                                    | All killed                                                                      | Boyce, Crossland and Shiff, 1966 |
|                  | Continuous application in 30 days |                            |                                                                                                                                                                                    | Fish survived; snails controlled                                                | Boyce, crossland and Shiff, 1966 |
| Cuprous chloride | 0.025                             | Reservoir; applied by boat | -                                                                                                                                                                                  | No fish died but there was a high mortality of snail                            | Muirhead-Thomson, 1971           |
|                  | 5                                 | Fish pond                  | No fish species in particular                                                                                                                                                      | <i>Limnaea peregrea</i><br>No harmful effect on either full grown or young fish | Deschiens and Floch, 1964        |
|                  | 2                                 | Fish pond                  | No fish species in particular                                                                                                                                                      | No harmful effect on either full grown or young fish                            | Deschiens and Floch, 1964        |

Source: Summarized from Muirhead-Thomson (1971).

Table 8.11. Molluscicides Marketed in the Philippines for the Control of a Herbivorous snail (*Pomacea* sp.) in Ricefields

| Common Name/<br>Active<br>Ingredient         | Formulation<br>(% ai) | Application Rate (kg ai/ha) Based on         |            |
|----------------------------------------------|-----------------------|----------------------------------------------|------------|
|                                              |                       | Recommended                                  | Calculated |
| Niclosamine (25%)                            | EC (55)               | 70–100 ml/10 L<br>(250 L sprayer<br>load/ha) | 0.58–0.82  |
| Methyl-isobutyl ketone (20%)<br>Ketone (10%) |                       |                                              |            |
| Metaldehyde                                  | WP (75)               | 70 g/16 L (250 L<br>sprayer load/ha)         | 0.7875     |
| Tannins, glycosides, stevols                 | WP (24.5)             | 20 kg/ha                                     | 4.90       |

and Wedgwood, 1989). Studies on mice showed that metaldehyde reduces brain concentration of neurotransmitters noradrenaline, serotonin, and gamma amino butyric acid. This depletion could be responsible for its convulsant properties (Mills, Bailey, McCrohan and Wedgwood, 1989). Unfortunately, very little information is known on the toxicity of metaldehyde to fish. At FAC-CLSU, about 40 percent of 0.68-g *O. niloticus* samples died within twenty-four hours after direct exposure to 1,320 ppm metaldehyde.

The molluscicide containing tannins, glycosides, and stevols was developed from natural toxins with specific properties against *Pomacea* sp., low mammalian toxicity, and high biodegradability.

In the Philippines, the forty-eight-hour  $LC_{50}$  values showed that two banned molluscicides were extremely and highly toxic to *O. niloticus* (30 g) (Table 8.12). Based on the recommended application rate, the computed field-application rate (0.10 kg ai/ha) of fentin chloride was lower than the twenty-four-hour  $LC_{50}$  (0.383–0.419 kg ai/ha) on *O. niloticus*. For fentin acetate, the field-application rate (0.135 to 0.18 kg ai/ha) is within the twenty-four-hour  $LC_{50}$  range (0.1145 to 0.2615 kg ai/ha).

Some of the presently available molluscicides have been found not so effective in controlling golden snails. As a result, farmers would use insecticides to control the pest at rates very much higher than the rate recommended for insect control. Rola and Pingali (1993) reported the increasing use of endosulfan (an organochlorine) as a molluscicide, also adding this as a case of misuse as endosulfan is registered only as an insecticide. There is hence a proposal to ban the importation of endosulfan in the country.

Table 8.12. Toxicity of Two Organostannous Molluscicides (Fentin Chloride and Fentin Acetate) to *O. niloticus* Compared to the Recommended Application Rates

| Molluscicide                                                       | Based on Cruz, Cruz, and Suñaz (1988) |                        | Toxicity Category                 |
|--------------------------------------------------------------------|---------------------------------------|------------------------|-----------------------------------|
|                                                                    | Time of exposure                      | LC <sub>50</sub> (ppm) | Based on 48-hr LC <sub>50</sub>   |
| Fentin chloride                                                    | 24                                    | 4.01 (3.83–4.19)       | Highly toxic                      |
|                                                                    | 48                                    | 3.97 (3.57–4.44)       |                                   |
|                                                                    | 96                                    | 2.58 (1.95–3.67)       |                                   |
| Fentin acetate                                                     | 24                                    | 0.345 (0.229–0.523)    | Extremely toxic                   |
|                                                                    | 48                                    | 0.185 (0.091–0.376)    |                                   |
|                                                                    | 96                                    | 0.092 (0.064–0.135)    |                                   |
| Computed Application Rate Based on the Recommended Rate (kg ai/ha) |                                       |                        | 24-hr LC <sub>50</sub> (kg ai/ha) |
| Fentin chloride                                                    | 0.10                                  |                        | 0.4010 (0.3830–0.4190)            |
| Fentin acetate                                                     | 0.135–0.18                            |                        | 0.1725 (0.1 145–0.2615)           |

Note: Average weight of *O. niloticus* = 30 g.

8.3.2. Pesticide Persistence and Degradation

Pesticide persistence in the aquatic environment mainly depends on the rate and frequency of application. In general, the higher the total amount of pesticides present in any given ecosystem, the higher is its bioaccumulation level (Matsumura, 1977). Ricefields receiving frequent application of insecticides would likely become pollutional to the aquatic biota. Hence, intensive rice farming areas where pesticides are commonly applied more than once may not appear compatible with fish farming. For one, persistent pesticide residues may tend to accumulate in fish. Also, they may undergo transformations or degradation due to photochemical, chemical, or biological reactions, during which the parent compound may be altered to one either more compatible or harmful to the environment (Duke, 1977, as cited in Khan, 1977). In addition, water temperature, pH and hardness, rice plants, aquatic weeds, and suspended organic matter and clay particles also contribute to pesticide degradation.

As such, the number of days for which the chemical toxicity of nonpersistent pesticides would persist in water is a valuable information to prevent fish mortality in integrated rice-fish farming systems (Cagauan and Arce, 1992). Pesticides that degrade in seven to ten days before fish introduction are suitable in

Table 8.13. Degradation Period of Fifteen Insecticides and One Rodenticide in Nonshaded and Shaded Tanks with Soil Substrate Using Nile Tilapia as Biological Indicator

| Pesticide            | Application Rate<br>(ppm of Formulated Product) | Degradation Period (days) |        |
|----------------------|-------------------------------------------------|---------------------------|--------|
|                      |                                                 | Nonshaded                 | Shaded |
| Insecticides:        |                                                 |                           |        |
| 1. Monocrotophos     | 2.27                                            | 1                         | -      |
| 2. Diazinon          | 0.1318                                          | 2                         | -      |
| 3. BPMC              | 0.2865                                          | 2                         | -      |
| 4. Carbofuran        | 0.56                                            | 4-5                       | -      |
| 5. MTMC + phenthoate | 17.0                                            | 5                         | -      |
| 6. MIPC              | 0.59                                            | 6-8                       | -      |
| 7. Azinphos-ethyl    | 0.1076                                          | > 6                       | -      |
| 8. Endosulfan        | 0.2119                                          | > 6                       | -      |
| 9. Methomyl          | 4.1315                                          | 13-15                     | -      |
| 10. Methyl parathion | 0.18                                            | 16-19                     | 27-41  |
| 11. MIPC             | 1.28                                            | 16-20                     | 20-22  |
| 12. Malathion        | 0.27                                            | 15-22                     | 31-33  |
| 13. Chlorpyrifos     | 1.32                                            | 17-19                     | -      |
| 14. Fenvalerate      | 0.92                                            | 19-24                     | 21-35  |
| 15. Permethrin       | 0.75                                            | 19-28                     | 75     |
| 16. Carbaryl         | 10.88                                           | 26                        | 38-39  |
| Rodenticide:         |                                                 |                           |        |
| Coumatetrahyl        | 0.27                                            | > 50                      | > 50   |
|                      | 0.001                                           | 9                         | 14     |

Sources: Reyes and Dela Cruz (1982-1983); Dela Cruz and Lopez (1982).

rice-fish farming. The shorter pesticide degradation period will allow more time for fish growth. This is particularly important when transplanted rice is grown for ninety days, allowing only eighty days (about 2.5 months) for the paddy fish to grow. The degradation period of nonpersistent pesticides would hence indicate the proper time to stock fish in rice-fish culture.

Table 8.13 presents the degradation period of seventeen insecticides and one rodenticide using Nile tilapia as biological indicator in nonshaded and shaded tanks with soil substrate. In nonshaded tanks, monocrotophos, diazinon, BPMC, MIPC (0.59 ppm f.p.), MTMC + phenthoate, and carbofuran insecticides all degraded in less than ten days; the others degraded in thirteen to twenty-eight

days. In shaded tanks, insecticide degradation ranged from twenty to seventy-five days.

On the other hand, it took more than fifty days to degrade coumatetralyl rodenticide (0.27 mg/l f.p.) in both non-shaded and shaded tanks. A reduction, however, of its concentration by almost 100 percent gave a degradation period of only nine days in nonshaded tanks and fourteen days in the shaded tanks.

Insecticide and rodenticide degradation period in nonshaded tanks were shorter than those in the shaded tanks, clearly revealing the role of solar radiation and temperature in pesticide degradation. In exposed field conditions where solar radiation can greatly increase water temperature, insecticides will degrade quicker than in shaded conditions when water temperature is low. Moreover in a rice-fish ecosystem, less persistent pesticides may easily be degraded when applied at the early stage of the rice crop when there is less plant canopy than when applied to matured rice plants during late infestation. Any insecticide drift under the heavy rice canopy of matured rice plants tends to degrade longer because of poorer light penetration and low water temperature. In such cases, pesticide particles may persist longer in the system, hence exposing the fish for an extended period. Most pyrethroids have a negative insecticidal temperature coefficients—that is, they are more toxic at lower temperatures (Leahey, 1985). Depending on the pesticide application rate, fish mortality may or may not occur. Fish survivors that have grown bigger may even tolerate subsequent insecticide applications. However, according to Matsumura (1977), although small fishes have relatively larger surface area, and also consume more food per unit body weight than do large fishes, the latter group tend to have greater toxicity tolerance and accumulate more pesticides in any ecosystem. Younger fish appear to be more affected by pesticide toxicity due to (1) a higher rate of metabolism and hence a higher food intake per unit body weight, (2) greater intake of the toxicant via gills because of the larger gill surface area relative to body mass in the smaller fish, and (3) a smaller lipid pool of the body, which can store only smaller quantities of the toxicant (Murty, 1986).

To better assess pesticide degradation, fish mortality and residues in water of some chemicals in unplanted paddies may be reviewed. Table 8.14 shows that MTMC + phenthoate (1.02 kg ai/ha), permethrin (0.10 kg ai/ha), and triazophos (0.06 kg ai/ha) were, respectively, degraded in four, seven, and nine days. When fish mortality was obtained in waters where no permethrin nor MTMC + phenthoate was detected, it was found that such nondetectability does not necessarily mean safety for fish.

In this line, instrument sensitivity becomes very important in determining the least possible concentration of chemical in the water. Furthermore, an ideal assessment of the pesticide degradation period should include monitoring of fish mortality and residue analysis in both live and dead fish. Fish mortality, how-



Table 8.14. Fish Mortality, Residues in Water, and Degradation Period of Some Insecticides in Unplanted Paddies

| <i>Time of Sampling</i> | <i>Permethrin<br/>0.10 kg ai/ha</i> |                                | <i>MTMC + phenthoate<br/>1.02 kg ai/ha</i> |                                | <i>Triazophos<br/>0.60 kg ai/ha</i> |                                |
|-------------------------|-------------------------------------|--------------------------------|--------------------------------------------|--------------------------------|-------------------------------------|--------------------------------|
|                         | <i>Dead Fish (%)</i>                | <i>Residues in Water (ppm)</i> | <i>Dead Fish (%)</i>                       | <i>Residues in Water (ppm)</i> | <i>Dead Fish (%)</i>                | <i>Residues in Water (ppm)</i> |
| 24 hrs                  | 100                                 | T                              | 96                                         | T                              | 93                                  | 4.253-4.367                    |
| 48 hrs                  | 92*                                 | T                              | 8                                          | N.D.                           | 88                                  | 0.584-0.312                    |
| 72 hrs                  | 14*                                 | N.D.                           | 0                                          | N.D.                           | 93                                  | 0.043-0.312                    |
| 96 hrs                  | 18*                                 | N.D.                           | 0                                          | -                              | 93                                  | 0.041-0.149                    |
| 5 days                  | 22*                                 | N.D.                           | 0                                          | -                              | 95                                  | 0.022-0.029                    |
| 6 days                  | 0                                   | -                              | 0                                          | -                              | 69                                  | T                              |
| 7 days                  | 0                                   | -                              | 0                                          | -                              | 39                                  | T                              |
| 8 days                  | 0                                   | -                              | 0                                          | -                              | 0                                   | N.D.                           |
| 9 days                  | 0                                   | -                              | 0                                          | -                              | 0                                   | N.D.                           |
| Degradation period      | 7 days                              |                                | 4 days                                     |                                | 9 days                              |                                |

Source: FAC, CLSU (1988); Cagauan and Arce (1992).

Notes: Number of replicates per chemical = 2. Figures in asterisks are mortalities from 1 plot.  
N.D.-nondetectable; T-trace.

Table 8.15. Degradation of Insecticides in Unplanted Paddies

| <i>Insecticide</i> | <i>Percentage ai</i> | <i>Application Rate (kg ai per ha)</i> | <i>Range of Degradation (days)</i> | <i>Number of Plots</i> |
|--------------------|----------------------|----------------------------------------|------------------------------------|------------------------|
| Azinphos-ethyl     | 40                   | 1.0                                    | 9-13                               | 3                      |
| Methyl parathion   | 50                   | 1.25                                   | 5                                  | 3                      |
| Monocrotophos      | 28.5                 | 0.7125                                 | 3                                  | 2                      |
| Triazophos         | 40                   | 0.60                                   | 13                                 | 2                      |
| MTMC + phenthoate  | 6                    | 1.02                                   | 1-6                                | 2                      |
| Permethrin         | 10                   | 0.10                                   | 6-7                                | 3                      |
| Cypermethrin       | 5                    | 0.05                                   | 3                                  | 2                      |

Source: Cagauan and Arce (1992).

ever, may seem to be a better gauge of pesticide degradation when instrument sensitivity to analyze residues is relatively low. Again, it should be noted that fully survived fish and absence of residues in water do not necessarily mean that fish did not accumulate any residue.

Table 8.15 presents degradation periods of other insecticides (without residue analysis) from unplanted paddies. At the recommended application rates, methyl

parathion, monocrotophos, MTMC + phenthoate, permethrin, and cypermethrin were all degraded within seven days. On the other hand, it took more than ten days to degrade azinphos-ethyl and triazophos.

From the above experiment, laboratory and field bioassay tests showed that azinphos-ethyl and triazophos, both OPs, were highly toxic to Nile tilapia resulting in mortality on direct exposure. The degradation period of these insecticides further showed their use will not be compatible with fish culture. Application rates meanwhile used for monocrotophos and methyl parathion (0.7125 kg ai/ha and 1.25 kg ai/ha, respectively) were higher than the recommended rates (0.43 kg ai/ha and 0.50 kg ai/ha, respectively). Both degradation test and recommended application rates of these two insecticides can cause fish mortality on direct exposure but do not pose a risk to fish after three to four days since their toxicity had already dissipated.

Koesoemadinata (1980) observed that granular organophosphates are lethal to fish in ricefields within four days after application, and endrin and endosulfan (both organochlorines) produced fishkills in ricefields within eleven and eighteen days, respectively. Further experiments demonstrated that the emulsifiable concentrate (EC) forms of these organochlorines killed fish within five to fifty days (Hardjamulia and Koesoemadinata, 1972).

In summary, degradation periods of the different insecticides in unplanted fields can be ranked as follows: carbamates, one to six days; synthetic pyrethroids, three to seven days; and organophosphates, three to thirteen days. In ricefields, recommended rates of synthetic pyrethroids were degraded faster (two days) compared to organophosphates (four days).

### **8.3.3. *Residue Analysis from Rice-Fish Experiments at FAC, CLSU***

**8.3.3.1. Two Insecticide Applications After Fish Stocking.** Table 8.16 shows results from two trials on fish mortality and residue analysis of both water and fish before insecticide application and twenty-four hours until five days thereafter. The insecticides were applied twice at seven to fourteen days after fish stocking (DAFS). No fish mortality was observed up to five days after the first and second applications of permethrin and cypermethrin. Using triazophos, fish mortality averaged 48.75 percent (from two trials) and 5.67 percent (from one trial) at 24 and 48 hours after application, respectively. Residues were not detectable in water and fish tissues five days after the first and second applications of the recommended rates of the insecticides tested.

**8.3.3.2. Insecticide Application One Week Before Fish Stocking and Application of Another Insecticide 7 DAFS.** A second experiment employed two

Table 8.16. Average Nile Tilapia Mortality and Residues in Water and Fish Tissues from Two Trials Receiving Two Applications of Recommended Rates of Insecticides

| <i>Insecticide/<br/>Application Rate</i> | <i>Time of Application</i> |             | <i>Time of Sampling<br/>After Application<br/>(in days)</i> | <i>Fish<br/>Mortality<br/>(%)</i> | <i>Residues (in ppm)</i> |             |
|------------------------------------------|----------------------------|-------------|-------------------------------------------------------------|-----------------------------------|--------------------------|-------------|
|                                          | <i>DAT</i>                 | <i>DAFS</i> |                                                             |                                   | <i>Water</i>             | <i>Fish</i> |
| Permethrin<br>0.10 kg ai/ha              | 15                         | 7           | BA                                                          | 0                                 | ND                       | ND          |
|                                          |                            |             | 1                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 2                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 4                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 5                                                           | 0                                 | ND                       | ND          |
|                                          | 29                         | 14          | BA                                                          | 0                                 | ND                       | ND          |
|                                          |                            |             | 1                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 2                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 4                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 5                                                           | 0                                 | ND                       | ND          |
| Cypermethrin<br>0.05 kg ai/ha            | 15                         | 7           | BA                                                          | 0                                 | ND                       | ND          |
|                                          |                            |             | 1                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 2                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 4                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 5                                                           | 0                                 | ND                       | ND          |
|                                          | 29                         | 14          | BA                                                          | 0                                 | ND                       | ND          |
|                                          |                            |             | 1                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 2                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 4                                                           | 0                                 | -                        | -           |
|                                          |                            |             | 5                                                           | 0                                 | ND                       | ND          |

|                             |    |    |    |                    |    |    |
|-----------------------------|----|----|----|--------------------|----|----|
| Triazophos<br>0.60 kg ai/ha | 15 | 7  | BA | 0                  | ND | ND |
|                             |    |    | 1  | 48.75 <sup>a</sup> | -  | -  |
|                             |    |    | 2  | 5.67 <sup>a</sup>  | -  | -  |
|                             |    |    | 4  | 0                  | -  | -  |
|                             |    |    | 5  | 0                  | ND | ND |
|                             | 29 | 14 | BA | 0                  | ND | ND |
|                             |    |    | 1  | 0                  | -  | -  |
|                             |    |    | 2  | 0                  | -  | -  |
|                             |    |    | 4  | 0                  | -  | -  |
|                             |    |    | 5  | 0                  | ND | ND |
|                             | 15 | 7  | BA | 0                  | ND | ND |

Source: Arce, Cagauan, Gamboa and Lucero (1987).

Note: DAT = days after transplanting, DAFS = days after fish stocking, BA = before application, ND = nondetectable.

a. = from one trial only.

applications of recommended rates of insecticides (Table 8.17). The first application of granular carbofuran was done at rice transplanting before fish stocking. Preemergent granular herbicide was also applied at transplanting. The second separate applications of azinphos-ethyl, methyl parathion, and monocrotophos were done seven days after fish stocking (DAFS). Results showed that carbofuran residues were not present in the water six days after application or a day before fish stocking. The second application however resulted to fish mortality within twenty-four hours after application in separate plots. Plots applied with 1.0 kg ai/ha azinphos-ethyl had 87.25 percent fish mortality within twenty-four hours of application. At this period, its residues in water ranged from 0.1322 to 0.2713 mg/kg, and from 0.0910 to 0.2112 mg/kg in whole dead fish. Methyl parathion (1.25 kg ai/ha) produced fish mortality rates of 25.25 percent and 44.75 percent, within twenty-four and fourteen-eight hours, respectively, after application. Its residues in water were 0.0578 to 0.0644 mg/kg within twenty-four hours of application. For the same period, methyl parathion residues in whole fish was 0.0479 to 0.0621 mg/kg. Monocrotophos (0.7125 kg ai/ha) produced a 21 percent fish mortality rate and water and whole fish residue levels of 0.110 to 0.0228 mg/kg and 0.010 to 0.0143 mg/kg, respectively, again within twenty-four hours after application. Five days after the second application, residue analysis revealed no detectable insecticide residue in water. At this period, fish survivors were absent in the azinphos-ethyl and methyl parathion treatments while some fish survived in the monocrotophos treatment.

Research results after the second application confirmed the acute toxicity of the insecticides on Nile tilapia (*O. niloticus*). Residues accumulated in the dead fish may not be significant as these are small and nonharvestable. However, these residues may present a human health hazard when the dead fish are collected and processed into fish paste ("bagoong"), fermented fish ("burong isda") or dried fish as some farmers would do. The amounts of methyl parathion and monocrotophos residues detected in dead fish within twenty-four hours after application are higher than the allowable daily intake (ADI) prescribed by WHO/FAO—0.02 mg/kg of body weight and 0.0005 mg/kg body weight, respectively. ARSAP/CIRAD (1988) defines a chemical's allowable daily intake (ADI) as the daily intake that, during an entire lifetime, appears to be without appreciable risk on the basis of all known facts at the time. In terms of pesticide residues, the acceptable daily intake is intended to give a reference maximum amount that can be taken daily in the food "without appreciable risk" to the consumer.

Other experiments at FAC-CLSU (Sevilleja, Monje, and Cagauan, 1989) showed that rates of cyfluthrin K + L, a synthetic pyrethroid (0.0625 and 0.0125 kg ai/ha) and cyfluthrin (0.0125 and 0.025 kg ai/ha) left no detectable amount of residue in water seven days after application made at thirty-five days after transplanting.

Table 8.17. Nile Tilapia Mortality, Residues of Insecticides Compared to Allowable Daily Intake (ADI) and Bioaccumulation Ratio in Controlled Rice-Fish Experiments Applied Two Times with Insecticides (from Two Trials)

| Insecticide/<br>Application<br>Rate | Application Time<br>DAT | DAFS | Sampling After<br>Application<br>(days) | Fish<br>Mortality<br>(%) | Residues (in ppm) | Fish              | Bioaccu-<br>mulation<br>Ratio | ADI<br>(mg/kg<br>body wt) |
|-------------------------------------|-------------------------|------|-----------------------------------------|--------------------------|-------------------|-------------------|-------------------------------|---------------------------|
| First application:                  |                         |      |                                         |                          |                   |                   |                               |                           |
| Carbofuran<br>1.0 kg ai/ha          | 0                       | 0    | -                                       | -                        | -                 | -                 |                               |                           |
|                                     |                         |      | BA                                      | -                        | ND                | -                 |                               |                           |
|                                     |                         |      | 13 DAT or                               | 0                        | -                 | -                 |                               |                           |
|                                     |                         |      | 6 DAFS                                  |                          |                   |                   |                               |                           |
| Second application:                 |                         |      |                                         |                          |                   |                   |                               |                           |
| AZinphos-ethyl<br>1.0 kg ai/ha      | 14                      | 7    | 1                                       | 87.25                    | 0.1322-0.2713     | 0.0910-0.2112     | 0.69-<br>0.78                 | ?                         |
|                                     |                         |      | 2                                       | 0                        | -                 | -                 |                               |                           |
|                                     |                         |      | 4                                       | 0                        | -                 | -                 |                               |                           |
|                                     |                         |      | 5                                       | 0                        | ND                | No fish survivors |                               |                           |
|                                     |                         |      | Total<br>87.25                          |                          |                   |                   |                               |                           |
| Methyl parathion<br>1.25 kg ai/ha   | 14                      | 7    | 1                                       | 25.25                    | 0.0578-0.0644     | 0.0479-0.0621     | 0.83-<br>0.96                 | 0.02                      |
|                                     |                         |      | 2                                       | 44.75 <sup>a</sup>       | -                 | -                 |                               |                           |
|                                     |                         |      | 4                                       | 0                        | -                 | -                 |                               |                           |
|                                     |                         |      | 5                                       | 0                        | ND                | No fish survivors |                               |                           |
|                                     |                         |      | Total<br>70.00                          |                          |                   |                   |                               |                           |
| Monocrotophos<br>0.7125 kg ai/ha    | 14                      | 7    | 1                                       | 21.00                    | 0.110-0.0228      | 0.01-0.0143       | 0.65-<br>0.91                 | 0.0005                    |
|                                     |                         |      | 2                                       | 0                        | -                 | -                 |                               |                           |
|                                     |                         |      | 4                                       | 0                        | -                 | -                 |                               |                           |
|                                     |                         |      | 5                                       | 0                        | -                 | -                 |                               |                           |
|                                     |                         |      | Total<br>21.00                          |                          | ND                | ND                |                               |                           |

Source: FAC-CLSU (1988).  
Note: DAT = days after transplanting, DAFS = days after fish stocking, BA = before application, ND = nondetectable.  
a. = from one trial only.

Other workers have shown that fish could bioaccumulate the insecticides within seven days of application but eventually degraded after this period. Celino, Gambalan, and Magallona (1987) reported that at the recommended rate of carbofuran, Nile tilapia (*O. niloticus*) did not show significant residues at harvest time. Varca and Magallona (1987) reported that the normal application rates of endosulfan, carbofuran, lindane, endosulfan, chlorpyrifos, BPMC, and carbosulfan was bioaccumulated at low levels in tilapia (*Oreochromis* sp.). It was not indicated, however, whether the size of tilapia was a fingerling or adult. Lou et al. (1991) reported that residues of fenitrothion (0.375-0.75 kg ai/ha) was less than 0.05 ppm in fish seven days after application, and further degraded to nondetectable levels in the harvestable fish toward the end of the crop period.

A review of research articles (some of which appear in Appendix D of this book) along the line of insecticide residues in freshwater fishes showed that the amount of bioaccumulation in fish depended on the type of environment where the experiment was conducted. Generally, residues of insecticides were high in simulated ecosystems such as aquaria and tanks rather than in field experiments with vegetation. Bioaccumulation occurred within one week and one month to most persistent insecticides in small fish but not in adult harvestable fish. Fish that are benthic feeders—such as those reported by Lucero (1980), like mudfish (*Ophicephalus striatus*), common carp (*Cyprinus carpio*), and Thai catfish (*Clarias batrachus*)—may have different accumulation rates compared to planktivorous fish. Planktivorous fish such as Nile tilapia and gourami (*Trichogaster pectoralis*), which are commonly found in ricefields, are smaller, hence they tend to be more sensitive to pesticide toxicity but accumulate less residues. Bottom-dwelling fishes such as those mentioned earlier are larger and tend to have higher bioaccumulation rate. Fish predators such as mudfish and catfish tend to stay in one place waiting for their prey, hence these fishes are more exposed and accumulate more of the pesticide.

Factors influencing the uptake of pesticides by fish are important in assessing the type of compounds one can apply and the size and species of fish one can culture in rice-fish farming systems. The influence of fish species to culture is influenced by hydrophobicity (lipophilicity) and water solubility of a compound (which in turn depend on the molecular structure), the lipid content, age, size, sex, and physiological activity of the fish. Environmental factors such as temperature also influence the rate of uptake of a xenobiotic chemical (Murty, 1986). The net assimilation of residues from food and tissue retention are dependent on size of the lipid pool (Roberts, de Frietas, and Gidney, 1977); the biological half-life is also dependent on the adiposity of the fish (Murty, 1986). This means that fatter fish have more tendency to accumulate more residues. The uptake of pesticide could also be influenced by the sex of fish. Hansen

(1980) reported that female *Gasterosteus* took up more lindane than the male and the latter took up about 5.8 times more lindane at the time of spawning than at other times. The pesticide uptake of male and female tilapia is unknown. Culture of all male tilapia in ricefields and ponds have been shown to give higher fish yields than mixed sexes.

The OPs and carbamates are generally taken up by fish at a lesser extent than OCs because the former have relatively higher water solubility (Lockhart, Memer and Grift, 1973; Seguchi and Asaka, 1981; Gray and Knowles, 1980, 1981, all cited in Murty, 1986). The uptake of residues of OCs by fish is rapid but their elimination is slow. Murty (1986) added that the time for achieving the highest levels of uptake and the extent of retention of OP residues by fish was directly related to the extent of persistence of a compound in water.

Pesticide residues absorbed by fish are metabolized and eliminated. Larger fish tend to take a longer time to eliminate the residues. Among the OCs, endosulfan is poorly metabolized and is mostly converted to endosulfan sulfate (Rao, Devi, and Murty, 1981). Pyrethroids are metabolized by fish through hydrolytic and oxidative processes (Leahey, 1985). Pyrethroids are rapidly metabolized just like the OPs (Murty, 1986), as they are highly lipophilic and readily partitioned from water into the blood via the gills (Leahey, 1985).

The elimination of pesticides in fish is through the gills and the renal pathways. The higher the polarity, the faster the elimination—for example, the elimination of lindane > dieldrin > DDT. Murty (1986) also explained that the elimination of pesticides in fish is a metabolic process and involves enzyme activity. Diazinon was degraded by the liver microsomal enzymes in fish (Fijii and Asaka, 1982; Hogan and Knowles, 1972). Freshwater fishes have more mixed function oxidase (MFO) than marine fishes, making the former less susceptible to OP and carbamate compounds (Fijii and Asaka, 1982). Carbofuran was metabolized by the microsomal-NADPH system in *Trichogaster pectoralis*; oxidative N-hydroxylation was the major route of metabolism of carbofuran (Gill, 1980).

## 8.4. General Synthesis

### 8.4.1. Pesticide Impact on Fish Farming in Ricefields

In general, insecticides, herbicides, and molluscicides prescribed for rice and their respective recommended rates are acutely toxic to fish on direct exposure. Recommended rates are markedly higher than the “safe” concentrations of the



pesticides based on the 1/10 or 1/100 of the forty-eight-hour  $LC_{50}$  from laboratory bioassays. This indicates that recommended rates can cause mortalities due to direct toxicity to fish. FAC-CLSU experiments have demonstrated that subsequent applications of insecticides after fish stocking resulted to immediate fish mortality.

One-time application at least seven to ten days before fish stocking using recommended rates of pesticide appeared to be suitable for fish culture. The time elapsed before fish introduction into the ricefield would allow the toxicity to dissipate preventing direct mortality to fish. Higher rates than the recommended tend to prolong degradation and will shorten the fish culture period resulting in small-size fish at harvest.

During subsequent applications of pesticide, fish can be concentrated in the pond refuge and the ricefield drained to minimize mortality during pesticide drift or leaching. Pesticide drift to adjacent areas could be reduced by using granular and systemic forms.

Bioaccumulation of insecticide by Nile tilapia generally occurred within twenty-four hours of application and resulted to mortality. Persistence of insecticides was observed within one week after application, and degradation immediately followed. A majority of the reports showed that fish did not contain any detectable amount of insecticide residues one week after application. After this period, any fish survivors reaching harvestable and edible size will unlikely accumulate residues if recommended rates of pesticides were used. It should be pointed out, however, that most of the insecticides tested were carbamates, organophosphates, and synthetic pyrethroids. Organochlorine insecticides, commonly known for their persistence, are not compatible with fish farming as they tend to bioaccumulate in fish.

Based on the foregoing discussion, the major considerations in the selection of pesticide in rice-fish farming are its low toxicity, short degradation period, and nonaccumulation in fish.

The impact on fish of pesticides presently recommended for rice is direct toxicity resulting in massive mortality rather than bioaccumulation in the harvestable fish. Bioaccumulation, however, in harvestable and edible-size fish may still occur with the use of nonpersistent insecticide with low toxicity if repeated applications are employed. The direct toxicity of pesticide could decrease fish yield or result to total loss. This consequence could undermine any economic benefits that the farmers can derive from the fish farming operation in ricefields. The adverse impact of pesticide on fish can also arise from indiscriminate use and misuse. Although farmers tend to underdose (Rola and Pingali, 1993), frequent pesticide application may prove detrimental to fish. Since most insecticides have a broad spectrum effect, uses other than as insecticide can be easily experimented by farmers.

#### 8.4.2. *Future Focus for Research*

Future studies should focus on the assessment of long-term effects of sublethal concentrations of pesticides in both laboratory and field conditions. Chronic toxicity is a long-term effect that could be related to changes in fish appetite, growth, metabolism, and reproduction and even death or mutations. Long-term life-cycle bioassay tests have an overall objective of determining maximum allowable toxicant concentration (MATC) of pesticide that may be present in a receiving water without causing any significant harm to fish and other components of the aquatic ecosystem. This test would also determine the right application factor for a particular pesticide. The application factor is applied to acute-toxicity tests to estimate toxicant concentrations that are safe for chronic or lifetime exposure of test organisms.

At present, available information on the residues of rice insecticides on fish are few and nil for herbicides and molluscicides. Information on acute toxicity of pesticides is available but not for new pesticides in the market. New rice pesticides are fast emerging in the market, and there is a need to test their acute toxicity to fish.

Field toxicity trials should take into consideration the contributing effects of physicochemical and biotic factors such as temperature, pH, water hardness, dissolved oxygen, turbidity, solar radiation, and particulate organic matter. Future experiments should be focused more on the effects of sublethal concentrations of pesticides and residue analysis on fish. Information derived from these two research aspects are vital in deciding the suitability of pesticides with fish farming in ricefields.

#### 8.4.3. *Fish Potential Role on Pest Control and IPM*

Waibel (1992) wrote that fish in ricefields can serve as a vehicle to speed up diffusion of integrated pest management (IPM) technology, as a “do not spray” strategy could be changed to a more attractive strategy—“grow fish.” Several experiments have shown the potential role of fish in pest control in ricefields and available information on this are found in Cagauan (1994). Chinese researchers for example have reported that rice insect predators were reduced by 12 to 75 percent with the introduction of fish into ricefields (Liao, 1980, as cited in Fedoruk and Leelapatra, 1992); and rice leafhoppers and rice striped disease incidence were reduced in comparative experiments of rice monocropping and rice-fish culture (Xu and Guo, 1992). Xu and Guo (1992) observed an increase in spider population in rice-fish plots. In another work in China, fish were found to predate on rice stemborers, rice leafhoppers, and rice planthoppers Spiller,

1985). Fish has also been reported to control weeds. Work done in Congo in 1960s showed that *Tilapia melanopleura*, at a density of three adult fish per acre stocked three weeks after transplanting of one-month old rice, controlled weeds and algae (Coche, 1967). Satari and Trimarini (1967) reported that weed production was reduced by 40 to 47 percent in mixed stocking of carp and tilapia compared to about 30 percent weed reduction when common carp was cultured alone. Cagauan et al. (1993) demonstrated that fish significantly reduced total weed abundance by 67 percent compared to about 18 percent reduction from herbicide. Several experiments showed that polyculture of fishes reduced weed infestation more than monoculture of fishes (Cagauan, 1991), particularly of nonherbivorous species such as Nile tilapia and common carp. These are some of the few available information along the potential role of fish in pest control in ricefields. Such role could be explored for pest management in ricefields.

## Notes

1. Lethal concentration of pesticide that results in 50 percent mortality of the test organisms.
2. One-tenth or 1/100 of the forty-eight-hour median lethal concentration ( $LC_{50}$ ) of the insecticides.

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# 9

## THE IMPACT OF PESTICIDES ON NONTARGET AQUATIC INVERTEBRATES IN WETLAND RICEFIELDS: A REVIEW

I.C. Simpson and P.A. Roger

### 9.1. Introduction

Aquatic invertebrates that inhabit the soil-floodwater ecosystem of wetland ricefields are considered important as nutrient recyclers, rice pests, biological control agents, food items, and vectors of human and animal diseases (Roger, Heong, and Teng, 1991). The functionality of this aquatic community depends on the relative and absolute population densities of the various groups and their activity rates. The widespread introduction of chemical pesticides to control rice pests (microbial pathogens, weeds, nematodes, snails, insects, and rodents) has significantly increased grain yields. However, because pesticides are often un-specific, they have the potential to profoundly modify the soil-floodwater communities of wetland ricefields. It is important to understand and predict how pesticide use affects the ecology of the ecosystem and to consider the implication of these changes for rice production and rice-producing environments.

#### 9.1.1. *Components of the Aquatic Macroinvertebrate Fauna*

Invertebrates that inhabit the soil-floodwater ecosystem of ricefields are derived from contiguous water bodies and span the whole spectrum of freshwater fauna

(Fernando, Furtado, and Lim, 1980). The dominant groups are crustaceans (crabs, crayfish, shrimps), microcrustaceans (ostracods, copepods, cladocerans), aquatic insect larvae (mosquitoes, chironomids), aquatic insects (coleopterans, hemipterans), molluscs (gastropods, bivalves), annelids (oligochaetes, leeches), nematodes and rotifers (Kurasawa, 1956; Heckman, 1974, 1979; Kikuchi, Furusaka, and Kurihara, 1975; Clement, Grigarick, and Way, 1977; Yatsumatsu, Hashimoto, and Chang, 1979; Fernando, Furtado, and Lim, 1980; Lim, 1980; Ishibashi and Itoh, 1981; Grant, Tirol, Aziz, and Watanabe, 1983; Grant, Roger, and Watanabe, 1985, 1986; Watanabe and Roger, 1985; Roger and Kurihara, 1988; Roger, Heong, and Teng, 1991; Simpson, Roger, Oficial, and Grant, 1993a, 1993b, 1994a, 1994b, 1994c).

Extensive species lists have been compiled for a ricefield in northeastern Thailand (Heckman, 1979) and a deepwater ricefield in Bangladesh (ODA, 1984). Crop cycle population dynamics of floodwater biota have been reported in temperate (Kurasawa, 1956; Ishibashi and Itoh, 1981) and tropical ricefields (Heckman, 1974; Grant, Tirol, Aziz, and Watanabe, 1983; Grant, Roger, and Watanabe, 1985; Ali, 1990; Simpson, Roger, Oficial, and Grant, 1993a; 1993b, 1994a, 1994b, 1994c). Density estimates for field populations of aquatic invertebrate are scarce and vary considerably between location, management strategies, stages of crop development, and sampling methods (Table 9.1).

### 9.1.2. *The Role of Aquatic Macroinvertebrates*

Aquatic invertebrates in ricefields contribute to nutrient cycling in several ways. Grazers and detritivores (microcrustaceans, insect larvae, gastropods, oligochaetes) perform important roles in the decomposition of the photosynthetic aquatic biomass (PAB), which develops in ricefield floodwater. Aquatic oligochaetes have an important role in ensuring the translocation of organic matter that accumulates in the detritus layer at the soil-water interface. Aquatic invertebrates also contribute to nutrient cycling through their bioperturbations, which release native minerals from the soil (Grant, Roger, and Watanabe, 1986) and through the decomposition and mineralization of their body tissues. Therefore aquatic and soil invertebrates are considered fundamental components of ricefield fertility (Roger, Grant, Reddy, and Watanabe, 1987; Roger and Kurihara, 1988).

When nutrients enter the floodwater they are potentially available for PAB development. If primary productivity increases, it encourages the proliferation of grazer populations, which may inhibit further algal growth and reduce biological N<sub>2</sub> fixation (Wilson, Greene, and Alexander, 1980). PAB that is not ingested will ultimately join the detritus pool, which is recycled more slowly. Any factor that changes the relationship between primary production and grazers could have important consequences for nutrient availability.

Table 9.1. Population Density Estimates of Aquatic Invertebrates in Wetland Ricefields

|                         |             |                                                   |
|-------------------------|-------------|---------------------------------------------------|
| Crustacean zooplankton: |             |                                                   |
| 200 to 800/L            | Japan       | Kikuchi, Furusaka, and Kurihara (1975)            |
| Cladocerans:            |             |                                                   |
| Daphnia 198/L           | Japan       | Kurasawa (1 956)                                  |
| Bosmina 15/L            | Japan       | Kurasawa (1956)                                   |
| max. 300/L              | Malaysia    | Ali (1990)                                        |
| 0 to 1,100/L            | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| 0 to 33,000/sq m        | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| copepods:               |             |                                                   |
| Cyclops 42/L            | Japan       | Kurasawa (1956)                                   |
| max. 800/L              | Malaysia    | Ali (1990)                                        |
| 0 to 1,700/L            | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| 0 to 40,000/sq m        | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| Ostracods:              |             |                                                   |
| 0 to 422/L              | Philippines | Grant, Tirol, Aziz, and Watanabe (1983)           |
| 10 to 20,000/sq m       | Philippines | Grant, Roger, and Watanabe (1986) <sup>a</sup>    |
| 300 to 37,000/sq m      | Malaysia    | Lim and Wong (1986)                               |
| 0 to 4,300/L            | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| 0 to 98,000/sq m        | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| Chironomid larvae:      |             |                                                   |
| max. 18,000/sq m        | California  | Clement Grigarick, and Way (1977)                 |
| 8,000/sq m              | Philippines | Grant, Roger, and Watanabe (1986) <sup>a</sup>    |
| 0 to 700/L              | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| 0 to 10,000/sq m        | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| Mosquito larvae:        |             |                                                   |
| 0 to 350/L              | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| 0 to 7,000/sq m         | Philippines | Simpson, Roger, Oficial, and Grant (1994b)        |
| Molluscs:               |             |                                                   |
| max. 1,000/sq m         | Philippines | Grant, Roger, and Watanabe (1986) <sup>a</sup>    |
| 0 to 1,500/sq m         | Philippines | Simpson, Roger, Oficial, and Grant (1994c)        |
| Oligochaetes:           |             |                                                   |
| max. 12,500/sq m        | Philippines | IRRI (1984)                                       |
| max. 18,500/sq m        | Philippines | IRRI (1985)                                       |
| max. 40,000/sq m        | Japan       | Kikuchi, Furusaka, and Kurihara (1975)            |
| 40 to 330/sq m          | India       | Senapati, Biswal, Sahu, and Pani (1991)           |
| 0 to 40,000 sq m        | Philippines | Simpson, Roger, Oficial, and Grant (1993a, 1994b) |

a. Quote in Grant, Roger, and Watanabe (1986) but previously unpublished

The role of aquatic oligochaetes in contributing to nutrient cycling and modifying biological activities in ricefields has received more attention than other invertebrate groups. Furthermore, research conducted on these organisms in other freshwater environments could be applicable to flooded ricefields. Potential roles and effects of aquatic oligochaetes in ricefields include: (1) stimulation of OM mineralization (Grant and Seegers, 1985a, 1985b); (2) biostratification of the soil (Davis, 1974; Kurihara and Kikuchi, 1980; McCall and Tevesz, 1982; Robbins, 1986; Kurihara, 1989); (3) reduction of weed abundance (Kikuchi, Furusaka, and Kurihara, 1975; Kurihara and Kikuchi, 1980; Kurihara, 1989); (4) destruction of the oxidized soil surface layer (Kurihara and Kikuchi, 1980); (5) enhancement of nutrient transfer across the soil-floodwater interface (Kurihara and Kikuchi, 1980; Kikuchi and Kurihara, 1982); (6) increased soil pH (Kikuchi, Furusaka, and Kurihara, 1977; Kurihara, 1989); (7) decreased soil Eh (Kikuchi, Furusaka, and Kurihara, 1977; Kurihara, 1989); (8) changes to soil microbial populations (Wavre and Brinkhurst, 1971; Kikuchi and Kurihara, 1977; Fukuhara, Kikuchi, and Kurihara, 1980; Kurihara and Kikuchi, 1980; Kurihara, 1989); (9) increased biotic and abiotic oxygen demand (Kikuchi, Furusaka, and Kurihara, 1977); (10) provision of a food source for aquaculture species (Aston, Sadler, and Milner, 1982; Marian and Pandian, 1984); and (11) enhancement of denitrification and nitrification in the soil (Chatarpaul, Robinson, and Kashik, 1980).

Flooded ricefields and irrigation schemes in tropical and subtropical regions create habitats favorable for the propagation of several invertebrates vectors and intermediate hosts of human and animal diseases (Roger and Bhuiyan, 1990). The most important groups are mosquito larvae and gastropod snails. Adult mosquitoes transmit malaria, encephalitis, filarial worms, dengue fever, yellow fever, and other diseases. Certain species of gastropod snails (*Oncomelania*, *Bilinus*, *Biomphalaria*, *Limnea* spp.) are intermediate hosts of parasitic trematode (Schistosomiasis) and nematode species that infect man.

Some invertebrate species that inhabit the floodwater are regarded as rice pests. Probably the most serious is the golden snail (*Pomacea canaliculata* Lamarck). It is a voracious herbivore that can devastate rice seedlings and cause yield losses of up to 40 percent (PDA and FAO, 1989). Chironomid larvae have been reported to inflict damage by feeding on germinating seeds and young seedlings (Clement, Grigarick, and Way, 1977). Barrion and Litsinger (1984) reported that chironomid larvae, ostracods, and corixids were observed to damage the roots of two-week-old rice seedlings.

The floodwater may contain a rich array of invertebrate predators, competitors, and parasites of pest and vector species. It is important to conserve these organisms as agents of biological control to suppress the development of deleterious organisms. For example, aquatic predators are reported to consume up to

90 percent of mosquito larvae that develop in the floodwater. If the natural predators are destroyed, the number of emerging mosquitoes could increase. Therefore, cultural practices favoring biological control agents should be encouraged (Mather and Trinh Ton That, 1984).

In traditional subsistence rice culture, farmers often depend on aquatic food items taken from their ricefields to supplement their diet. Invertebrates such as snails, crabs, and crayfish are consumed directly, others are important as prey items for harvested vertebrate species such as frogs, fish, and ducks.

### *9.1.3. Factors Affecting Pesticide Hazard in Ricefields*

Results of studies on the impact of pesticides on nontarget organisms in wetland ricefields must be interpreted carefully to avoid erroneous conclusions. Factors to be considered include the chemicals, rate and frequency of applications, nature of the impact, agroenvironmental conditions, and methodology.

Pesticides applied in ricefields include: insecticides, herbicides, fungicides, molluscicides, rodenticides, and nematicides. Insecticides are potentially the most toxic to aquatic invertebrates. All categories of insecticides (organochlorines, organophosphates, carbamates, pyrethroids, and insect growth regulators) are currently in use in ricefields. Each pesticide category contains a multitude of different chemicals, and care should be taken to avoid generalizations about pesticide impacts without reference to the actual chemical involved. These chemicals are applied at different rates and frequencies, in various combinations, in different formulations, and by different methods. It is important to appreciate the possible implications of these differences to recognize potential pesticide impacts on nontarget organisms.

Pesticide impacts on aquatic invertebrates have often been reported where experimental concentrations are considerably higher than those resulting from field applications at recommended rates. Such information is useful in the context of pesticide misuse and accidental spillages, but where pesticides are used judiciously the findings are of limited value. However, it should also be appreciated that farmers' application rates and recommended rates are often different. Pesticides are sometimes applied at higher than recommended rates, in the belief that they will be more effective. Conversely, some farmers apply pesticides at lower than recommended rates to reduce costs.

Quantifying pesticide inputs for comparative purposes is difficult because one application of pesticide X at 2 kg ai/ha, two applications of X at 1 kg ai/ha, and one application of Y at 2 kg ai/ha will probably all have different effects. Consequently, quantification in terms of total amount or frequency of application is not fully satisfactory. The problem is compounded when different pesticides

are applied in combination with each other; antagonistic or synergistic activities are largely undocumented.

It is important to know the formulation, method of application, and solubility of a pesticide. Solvents used with emulsifiable concentrates are often toxic themselves. Pesticides in ricefields can be sprayed, broadcast, incorporated in the soil, or used for dipping rice seedlings at transplanting. Carbamates and organophosphates are considered less toxic in ricefields if applied in granular form (Arce and Cagauan, 1988). Incorporation (Siddaramappa and Seiber, 1979) or deep-placement (Siddaramappa, Tirol, and Watanabe, 1979) of carbofuran reduced its concentrations in floodwater and increased its persistence in soil. When pesticides are sprayed late in the crop cycle, it has been suggested that a significant proportion is intercepted by the rice canopy and that little of it reaches the floodwater. When applied as granules, more of it enters the floodwater, although interception of carbofuran granules by floating macrophytes and rice plants has been reported (Lim, Abdullah, and Fernando, 1984; Ali, 1990). Once a pesticide has entered the floodwater, its toxicity is dependent on its solubility; carbaryl is less soluble than carbofuran and therefore less available to water-column invertebrates. As pesticides degrade, decomposition products form that are often toxic themselves, sometimes more toxic than the parent chemical.

The nature of pesticide impacts on nontarget organisms can be nominally divided into lethal, sublethal, or indirect effects. Lethal effects are observed when pesticide concentrations are sufficient to cause mortality directly. Sublethal effects include alteration of behavioral and physiological activities, interference with reproduction and maturation, and morphological changes. Sublethal impairment can reduce the chances of survival for the individual and the population. The most commonly perceived indirect pesticide effects in ricefields are reductions in species diversity, changes in community structure, and proliferation of selected species (Ishibashi and Itoh, 1981; Roger and Kurihara, 1988; Roger, Heong, and Teng, 1991). It can not be concluded that pesticides have no impact simply because no mortality was observed.

Information on pesticide impacts on aquatic invertebrates in farmers' ricefields or in fields managed according to farmers' usual practices is scarce. Literature that reports the results of laboratory studies can be extrapolated to ricefield conditions only with extreme caution. Pesticides behave differently under field conditions and the degree of exposure of an organism will be dependent on its behavior, habitat, and food preferences (Lim, Abdullah, and Fernando, 1984). Smith and Ison (1967) concluded that benthic organisms were exposed to higher concentrations of pesticide residues and for longer periods than those inhabiting the water-column. Consequently, sensitivity to a particular chemical in laboratory tests is not necessarily observed under field conditions.

The impact of pesticides in the floodwater ecosystem of ricefields is

dependent on an array of agroenvironmental parameters, including temperature, radiation, pH, soil type, crop and water management, and crop development. Behavior and persistence of pesticides in rice-based ecosystems are discussed in detail in Chapter 5. However, it is important to draw attention to some aspects of particular relevance to their potential impact on aquatic invertebrates. Pesticide concentration in the floodwater is highly dependent on water depth; if depth is doubled the maximum potential concentration is halved. Fertilizer management should be considered carefully in field experiments. Direct interactions with pesticides are unlikely, but there is evidence that aquatic invertebrates are affected more by nitrogen-fertilizer than pesticides when applied at realistic doses (Simpson, Roger, Oficial, and Grant, 1994b, 1994c). The closure of the rice canopy has implications for many floodwater parameters and pesticide interception, therefore the timing of pesticide applications relative to crop development should be afforded due consideration.

Sampling methodology and the manner in which data are presented could significantly alter the results and conclusions drawn from field experiments. Literature values of floodwater invertebrate densities have been presented in volume (Kurasawa, 1956; Kikuchi, Furusaka, and Kurihara, 1975; Ali, 1990) and spatial terms (Grant, Tirol, Aziz, and Watanabe, 1983; Grant, Roger, and Watanabe, 1986; Lim, 1980; Lim and Wong, 1986; Simpson, Roger, Oficial and Grant, 1993a; 1993b, 1994a; 1994b; 1994c). Expression of densities in volumetric terms is intrinsically erroneous unless floodwater depth is constant; doubling the water depth by irrigation will halve population densities.

## 9.2. The Impact of Pesticides on Aquatic Invertebrates

### 9.2.1. Floodwater Invertebrates

The most commonly reported impact of insecticides on floodwater invertebrates in ricefields is a proliferation of primary consumers after a transient decrease (Lim, 1980; Ishibashi and Itoh, 1981; Roger and Kurihara, 1988; Roger, Heong, and Teng, 1991). Ostracod (*Stenocypris major*) densities in Malaysian ricefields averaged 10,000/sq m in control and 21,000/sq m in carbofuran (0.2 percent ai/ha) treated plots (Lim and Wong, 1986). Ostracods were reported to be abundant in insecticide-treated ricefields in the Philippines (IRRI, 1986). Explanations for the proliferation of ostracods after insecticide applications include insecticide resistance, reduced competition and predation, high tolerance of juveniles relative to adults, parthenogenetic reproduction, and increased fecundity (Khudairi and Ruber, 1974; Wong, 1979; Lim, 1980 Grant, Tirol, Aziz, and Watanabe, 1983; Lim and Wong, 1986).



Application of the herbicide benthocarb to experimental ricefields in Japan drastically reduced populations of snails, cladocerans, odonatan, midges, and mosquito larvae. Resurgence of midges, cladocerans, and mosquito larvae occurred rapidly to densities exceeding those of the controls (Ishibashi and Itoh, 1981). Lim (1980) found that nematodes, hemipterans, and dipterans dominated in nontreated fields whereas ostracods, dipterans, and conchostracans dominated in fields when pesticides were applied at the recommended dose. Total zooplankton decreased from 1,500 per li to 400 per li after the application of carbofuran but recovered within two weeks, largely due to the resurgence of ostracods and chironomid larvae. Subsequent applications of endosulfan and carbaryl produced inconclusive results and no apparent impact, respectively. It was considered that the carbaryl had no impact because it was applied as a spray, which was intercepted by the rice plants and prevented from entering the floodwater. The resurgence of chironomid larvae and ostracods was also reported in Japanese ricefields when predatory invertebrates such as Odonata larvae were decreased following the application of a mixture of propoxur, thiobencarb, and simetryne (Takamura and Yasuno, 1986). Grigarick et al. (1990) reported that the fungicide triphenyltin hydroxide (TPTH) adversely affected a wider range of microcrustaceans than a chitin synthesis inhibitor Benzoylphenyl urea (BPU) and that mosquito larvae (*Culex tarsalis*) resurged due to reduced predation.

Sato and Yasuno (1979) found that the concentrations of several insecticides in the floodwater of Japanese ricefields were higher than acutely toxic concentrations determined in the laboratory for five species of chironomid larvae. Gorbach, Haaring, Knauf, and Werner (1971) observed mortality of Coleoptera and Tipulidae larvae after an application of endosulfan (0.5 kg ai/ha) in a ricefield in Indonesia. Hydrocorisidae and Cyclopidae showed no sign of mortality. Applications of fenitrothion temporarily reduced the population of the zooplankton *Moina* sp. in a Japanese ricefield (Takaku, Takahashi, and Otsuki, 1979). Rotifers, cladocerans, and copepod populations were reported to be adversely affected when carbofuran was applied at 5.6 kg ai/ha in a Malaysian ricefield (Ali, 1990). Carbofuran applied at manufacturers' recommended rates was not acutely toxic to cladocerans in a Malaysian ricefield, but populations were indirectly suppressed later in the growing season (Lim, Abdullah, and Fernando, 1984).

Total biomass of aquatic invertebrates was significantly reduced by application of carbofuran (1 kg ai/ha) to a ricefield in Senegal (Mullie et al., 1991). Nontarget invertebrate taxa in Californian ricefields were reduced by 57 percent and abundance by 67 percent when TPTH was applied. With the exception of some benthic and crustacean species, the community had recovered after fifty days.

Simpson, Roger, Oficial, and Grant (1994b) studied the impact of realistic carbofuran and butachlor application regimes on the population dynamics of floodwater invertebrates in Philippine ricefields. Significant pesticide effects were

observed on ostracod, copepod, cladoceran, and chironomid, and mosquito larvae populations. However, the impacts were relatively small, transient, and inconsistent. It was concluded that at realistic application rates carbofuran and butachlor did not effect crop cycle population dynamics of floodwater invertebrates.

Snails are not usually affected directly by conventional rice insecticides and herbicides, but their populations may increase because of reduced competition. Gastropod populations showed no signs of mortality after endosulfan application in Indonesian ricefields (Gorbach, Haaring, Knauf and Werner, 1971). Molluscs were reported to be abundant in insecticide-treated ricefields in the Philippines (IRRI, 1986). In India, Roger, Grant, and Reddy (1985) observed that molluscs (*Limnea* and *Vivipara*) were abundant in BHC-treated plots. After harvest, Ishibashi and Itoh (1981) observed larger snail populations in fields previously treated with the herbicide benthocarb than in the control. Simpson, Roger, Oficial, and Grant (1994c) found little evidence that indigenous snail populations were affected by carbofuran or butachlor applications. The incidence of pesticide impacts on nontarget indigenous molluscs is likely to increase with the increasing use of molluscicides to combat the golden snail problem.

Aquatic invertebrate groups found in the floodwater of ricefields are common to many shallow freshwater ecosystems. Given the relative dearth of information available on *in situ* toxicity of pesticides in the floodwater of ricefields, useful insight into potential pesticide impacts can be obtained from field and laboratory experiments pertaining to these habitats. Crosby and Mabury (1992) reviewed the potential impacts of pesticides commonly used in Californian ricefields (molinate, thiobencarb, MCPA, londax, carbofuran, and methyl parathion) in this manner.

Pesticide impacts reported on aquatic invertebrates in other shallow freshwater ecosystems include no effect, differential mortality and recovery patterns between species and life stages, feeding effects, changes in population density and community structure (Hurlbert et al., 1970; Hurlbert, Mulla, and Wilson, 1972; Gliwicz and Sieniawska, 1986; Day and Kaushik, 1987; Helegen, Larson, and Anderson, 1988; Mani and Konar, 1988; Day, 1989; Hatakeyama and Sugaya, 1989; Wijrngaarden and Leeuwangh, 1989; Neugebauer, Zieris, and Huber, 1990; Hanazato and Yasuno, 1990a, 1990b, 1990c; Hanazato, 1991).

Many laboratory studies have been performed to investigate pesticide toxicity to aquatic invertebrates found in ricefields. Barrion and Litsinger (1982) found that carbofuran was acutely toxic to ostracods, chironomid larvae, corixids, and some predatory insects at 0.75 kg ai/ha. Grant, Roger, and Watanabe (1983) determined the toxicity of carbofuran and endosulfan to two species of ostracods recorded in ricefields; 48-hour LC<sub>50</sub> values ranged between 0.34 to 4.0 mg/L and 3.0 to >56.0 mg/L, respectively. These values are relatively high, indicating that ostracods are resistant to some conventional pesticides (Grant, Roger, and Watanabe, 1986). Filtration and assimilation rates of algae by cladocerans and

copepods are affected, not always negatively, by low concentrations of the pyrethroid fenvalerate (Day, Kaushik, and Solomon, 1987). Pyrethroids were acutely toxic to species of cladocerans and copepods between 0.12 and 5.0 ug/L and reduced reproductive and filtering rates at  $< 0.01$  ug/L (Day, 1989). Carbaryl and endosulfan inhibited growth and egg production of a cladoceran species (Krishnan and Chockalingam, 1989). Crayfish did not suffer mortality when exposed to carbofuran (0.2-0.8 mg/L) in field and tap water static bioassay tests (Andreu-Moliner, Almar, Legarra, and Nuñez, 1986).

### 9.2.2. *Soil Invertebrates*

The soil fauna in wetland ricefields is dominated by aquatic oligochaetes and nematodes. Nontarget effects of pesticides on nematodes in ricefields has received very little attention. Ishibashi and Itoh (1981) found no effect of the herbicide benthicarb on average population densities of saprophitic and parasitic nematodes in a Japanese ricefield. Among a plethora of biocidal chemicals applied to irrigated ricefields in the Philippines only monocrotophos and ethofenprox provided limited evidence of impacts on nematode population densities (Prot and Matias, 1990).

Information about pesticide impacts on populations of aquatic oligochaetes in ricefields is also scarce. Application of endosulfan to a ricefield in Indonesia did not cause Tubificidae mortality (Gorbach, Haaring, Knauf, and Werner, 1971). The recent disappearance of aquatic oligochaetes from some Japanese ricefields is thought to be associated with the use of some pesticides. This conclusion was arrived at when oligochaetes reappeared soon after a change in the type of herbicide applied and was supported by laboratory tests (Kurihara and Kikuchi, 1988).

In Philippine ricefields, a pesticide regime consisting of carbofuran, butachlor, and triphenyl tin hydroxide, applied at recommended rates, reduced aquatic oligochaetes population density over the cropping season from 1,800/sq m to less than 200/sq m (Roger et al., 1992). In a two-year study of the combined impacts of pesticide and nitrogen fertilizer management, aquatic oligochaete populations were adversely affected by carbofuran applications (0.6 to 2.5 kg ai/ha) during the first crop, but possibly stimulated during the second year (Simpson, Roger, Oficial, and Grant, 1993a). The adverse effects observed were manifest as interference with population development not reductions in population densities. A survey of aquatic oligochaetes in farmers' fields in the Philippines did not identify differences between populations attributable to pesticide use (Simpson, Roger, Oficial, and Grant, 1993b).

Earthworm mortality was reported in Texan ricefields after a carbofuran application of 0.56 kg ai/ha (Flickinger, King, Start, and Mohn, 1980). In Indian

ricefields, 6 and 34 percent reductions in population densities of *Darwida willsi* Michaelsen were reported after malathion applications of 0.75 and 3.0 kg ai/ha, respectively (Senapati, Biswal, Sahu, and Pani, 1991).

To gain further understanding of the likely impacts of pesticides on aquatic oligochaetes in ricefields one must refer to literature from similar ecosystems and laboratory tests. Pesticide stimulation and depression of burrowing activity has been reported in contaminated lake sediments (Keilty, White, and Landrum, 1988a, 1988b, 1988c; Keilty and Landrum, 1990). Whitley (1968) observed that the respiration rates of lumbricid and tubificid worms were increased in the presence of aqueous pollutants. Exposure to sublethal concentrations of some pesticides has been shown to increase reproductive activity, suggesting a response to compensate for chemical stress (Senapati, Biswal, Sahu, and Pani, 1991). Pesticide tolerance of some oligochaetes has been shown to increase with long-term exposure to low concentrations (Keilty and Landrum, 1990). Some oligochaetes are more tolerant of toxicants in polycultures than in monocultures (Chapman and Brinkhurst, 1984; Keilty, White, and Landrum, 1988a).

Pesticide impacts on aquatic oligochaetes reported from laboratory toxicity tests across a range of chemicals and concentrations include: death, hyperactivity, muscular spasms and convulsions, and reversible and nonreversible morphological changes (Whitten and Goodnight, 1966; Whitley, 1968; Naqvi, 1973; Magallona, 1989). Several authors have suggested that aquatic oligochaetes possess a greater tolerance of pesticides than other aquatic invertebrates (Naqvi, 1973; Bailey and Lui, 1980).

### 9.2.3. Biodiversity

It is generally accepted that crop intensification and agrochemical use decrease biodiversity and provoke "blooms" of individual species. However, quantitative data on aquatic invertebrate diversity in ricefields are rare. Furthermore, the limited amount of data available were obtained by different methods of sampling, over different time frames and from different locations.

The only reference on the diversity of aquatic invertebrates in traditional ricefields is a 1975 study by Heckman (1979) in Thailand where 183 species (protozoans excluded) were recorded in one field within one year. In a two-year study of the aquatic invertebrate community in ricefields in Selangor, Malaysia, Lim (1980) found that species heterogeneity decreased after a granular application of carbofuran, but that total invertebrate populations increased because of a rapid recruitment of ostracods. The total number of aquatic invertebrate taxa recorded was thirty-nine. Single sampling by Takahashi, Miura, and Wilder (1982) in four Californian ricefields recorded 10–21 taxa. In surveys of 18 sites in the Philippines (IRRI, 1986) and India (Roger, Grant, and Reddy, 1985;

Roger, Grant, Reddy, and Watanabe, 1987), it was found that population dominance was inversely proportional to diversity and that ostracods, chironomids, and molluscs dominated the invertebrate community at most sites, with a few species attaining exceptionally high densities at some sites. The highest number of taxa recorded at a site was twenty-six, the lowest, two.

The marked decrease in values recorded since 1975 might be taken as a rough indication of a decrease in species richness. This agrees with but does not demonstrate the generally accepted concept that crop intensification has reduced biodiversity in ricefields (Roger, Heong, and Teng, 1991). Decrease of biodiversity in ricefields may also be attributed to the disappearance of permanent reservoirs of organisms in the vicinity of the fields (Fernando, Furtado, and Lim, 1979).

#### 9.2.4. *Bioconcentration*

Pesticide uptake by aquatic animals is primarily through ingestion and absorption through respiratory organs. Once within an organism they can accumulate in body tissues, particularly fat. Bioconcentration of pesticides in food chains has been demonstrated in many ecosystems but has received little attention in ricefields. Available data refer to pesticide accumulation *in vitro* by BGA common in ricefields (Das and Singh, 1977; Kar and Singh, 1979). The ability of microalgae to accumulate pesticides has also been demonstrated in freshwater environments (Wright, 1978). Invertebrate grazers feeding on contaminated algae may ingest significant quantities of pesticide. Predatory invertebrates that consume herbivores are similarly at risk. Chen, Hsu, and Chen (1982) observed thiobencarb bioconcentrations thirty times above ambient in dragonfly naiads in a model ricefield ecosystem.

Bioconcentration of pesticides is important when considering the ricefield ecosystem as a possible environment for aquaculture (rice-fish, rice-shrimp). Sastrodihardjo, Adianto, and Yusoh (1978) found that the application of endrin and phosphamidon affected fish directly and indirectly through feeding on contaminated *Tubifex* sp.. Pesticide bioaccumulation in the worms' body tissues may account for this observation.

### 9.3. The Implications of Pesticide Impacts on Aquatic Invertebrates in Ricefields

#### 9.3.1. *Soil Fertility*

At current application rates of inorganic fertilizer, most nitrogen absorbed by the rice crop originates from the soil. Available soil nitrogen is released by the

turnover of a microbial biomass that represents only a few percent of total soil nitrogen (Watanabe, De Datta, and Roger, 1988). The microbial biomass is replenished by the recycling of (1) crop residues, (2) nutrients from the PAB, and (3) rhizosphere exudates. Therefore invertebrates play an important role in maintaining soil fertility when involved (1) in the recycling of nutrients from the PAB and detritus by grazing and (2) in the translocation of nutrients to the deeper soil layer where they contribute to the replenishment of the microbial biomass. Pesticide effects on grazer populations might affect algal primary production and nutrient recycling in floodwater. Pesticide effects on benthic feeding detritivores could have implications for the quantity of nutrients immobilized in the detritus layer and for the translocation of material across the soil-water interface. These effects probably have implications for soil fertility, especially nitrogen availability, but little data is available.

Most available information refers to the impacts of insecticides on algal grazers and the consequent effects on microalgae and  $N_2$ -fixing cyanobacteria. A commonly reported phenomenon is the development of algal blooms due to reduced grazing (Raghu and MacRae, 1967; Grant, Roger, and Watanabe, 1983; Grant, Roger, and Watanabe, 1986). Increased nitrogenase activity in the water of a ricefield treated with carbofuran (6 kg ai/ha) was attributed to inhibition of micro-crustaceans and consequent buildup of nitrogen-fixing blue-green algae (Tirol, Santiago, and Watanabe, 1981). This effect was, however, reported only after the first application of HCH or carbofuran. After repetitive applications, grazers, especially ostracods, resurged and algal growth was suppressed (Roger and Kurihara, 1988). This may have implications for the quantity of  $N_2$  fixed by cyanobacteria. Because of the relative higher resistance to grazing of cyanobacteria forming mucilaginous colonies, the resurgence of grazers has a selective effect on cyanobacteria flora and leads to the dominance of mucilaginous forms, which are usually less active in biological  $N_2$  fixation (Antarikanonda and Lorenzen, 1982; Grant, Roger, and Watanabe, 1985). The structure of the algal community may also be changed when pesticide impacts only occurs on specific grazer species. Changes in floral populations will eventually feedback on invertebrate grazers, ultimately returning the system to a new equilibrium.

### 9.3.2. *Disease Vectors and Intermediate Hosts*

The possible nontarget effects of pesticides on disease vectors and intermediate hosts in ricefields include transient population decrease, proliferation if natural predators and competitors are adversely affected, and resurgence of resistant strains.

Mosquito larvae populations, suppressed by natural enemies in traditional

ricefields, can develop large populations in intensive irrigated systems (Heckman, 1979; Lim, 1980; Grant, Roger, and Watanabe, 1983; Takamura and Yasuno, 1986; Roger and Kurihara, 1988). Broadcast application of nitrogen fertilizer leads to the proliferation of mosquito larvae (Simpson, Roger, Oficial, and Grant, 1994b). Disease problems associated with the proliferation of mosquito larvae in intensive irrigated rice systems are especially acute where urbanization has occurred in rice-growing regions, bringing humans and pests closer together.

Mulla and Lian (1981) observed that agricultural insecticide applications were directly toxic to mosquito larvae and adults and their predators. Whether or not the application of pesticides in ricefields for agricultural purposes is beneficial to vector control depends on their relative impact on vectors and predators. Reductions in the incidence of malaria and Japanese encephalitis have been reported in Japan since 1945. This could be attributed to the reduction of mosquito vector populations by agricultural insecticides (Self, 1987; Mogi, 1987). In Korea, agricultural pesticide application reduced the density of the Japanese encephalitis vector *Culex tritaeniorhynchus* in rice-growing areas but had no effect on the main malaria vector *Anopheles sinensis* (Self, 1987). The decrease of *C. tritaeniorhynchus* after 1970 in Japan could be attributed to the switch from organochlorine to carbamate pesticides that have less adverse affects on vector predators (Wada, 1974; Mogi, 1987).

Mosquitoes are particularly adept at producing strains resistant to conventional insecticides. In the rice-growing areas in the United States, the elimination of malaria by suppressing the vector with DDT in the post-World War II era led the way to extensive insecticide use against mosquitoes and agricultural pests. Organochlorine, organophosphate, carbamate, and synthetic pyrethroid insecticides have been used extensively enough in the United States to produce resistance in some riceland mosquitoes (Bown, 1987).

There is no available literature on the nontarget impacts of pesticides on gastropod intermediate host species. However, evidence from other species suggests that pesticides, with the exception of molluscicides, may have little effect or induce population increases (Gorbach, Haaring, Knauf, and Werner, 1971; Ishibashi and Itoh, 1981; IRRI, 1986; Roger, Grant, and Reddy, 1985; Simpson, Roger, Oficial, and Grant, 1994c). Increasing use of molluscicides to combat golden snails may increase the incidence of negative nontarget effects of pesticides on intermediate host species.

#### 9.4. Conclusions and Proposed Research Strategy

Despite the recognized importance of aquatic invertebrate populations in wetland ricefields, current knowledge on pesticide impacts is too fragmentary to draw definitive conclusions. Furthermore, available information deals almost exclusively

with insecticide in transplanted irrigated rice, whereas foreseeable changes in rice technology and pesticide use indicate a shift toward direct seeded rice with an increased use of herbicides and, possibly, molluscicides. Simultaneously, insecticide use is expected to decrease, with increased adoption of integrated pest management (IPM) and biological control. Therefore, it is difficult to recommend pesticide practices in the context of the management of nontarget aquatic invertebrate fauna.

It is also important to emphasize that impacts on nontarget organisms in wetland ricefields can be beneficial, detrimental, or both. If disease vectors or pest species are adversely affected, the impacts will be beneficial. However, should there be damaging effects on the nutrient recyclers, agents of biological control, and food species, the consequences will be detrimental. When beneficial and deleterious biota are affected simultaneously the desirability of the impact becomes a value judgment. If impacts are better understood, pesticide management could be developed to favor beneficial organisms without promoting deleterious organisms.

Laboratory research has studied the roles of aquatic invertebrates in ricefields and the tolerance of individual species to selected pesticides. It is important that more research be conducted *in situ* to quantify the impacts of pesticides on the various roles of aquatic invertebrates under realistic field conditions and cultural practices. Particular attention should be given to the long-term effects of pesticide applications on nutrient cycling and disease vectors.

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# 10 THE IMPACT OF PESTICIDES ON RICEFIELD MICROFLORA: AN ANALYTICAL REVIEW OF THE LITERATURE

P.A. Roger

## 10.1. Introduction

The 60 percent increase in rice production needed to meet the requirements of a fast-growing human population in the next thirty years (IRRI, 1990) should be obtained with practices that maintain or enhance the quality of the environment and conserve or enhance natural resources. Alterations in soils caused by crop production techniques that use high inputs of agrochemicals are not necessarily undesirable, especially as crop intensification produces more food on less land. But there is no assurance that, in the long term, crop intensification will not affect soil fertility.

At the levels of inorganic fertilizer usually applied in ricefields, most N absorbed by the plant originates from soil where it is released by the turnover of a microbial biomass that represents only a few percent of total soil N (Watanabe, De Datta, and Roger, 1988). Crop residues, rhizosphere exudates, algae, and aquatic plants contribute nutrients that allow the replenishment of microbial biomass. Nutrients accumulating in algae and aquatic plants—including biologically fixed  $N_2$ —and in the detritus layer at the soil-water interface are recycled by zooplankton and reincorporated into the soil by oligochaetes, which are therefore key components of the ricefield fertility (Roger and Kurihara, 1988).



Therefore it is important to understand and predict how factors associated with crop intensification, especially pesticide use, may affect the soil microbial biomass directly through toxic effects, or indirectly by decreasing the productivity of the photosynthetic aquatic biomass and inhibiting invertebrate populations responsible for nutrient recycling and translocation. There is also a concern about the enhanced use of pesticides that might lead to a reduced pesticide efficiency because of shifts in microbial populations toward organisms more efficient in pesticide degradation.

Aspects dealing with pesticide impacts on soil and water micro and mesofauna are reviewed by Simpson and Roger (Chapter 9). Those dealing with pesticide degradation by microorganisms are reviewed by Roger and Bhuiyan (Chapter 5). This chapter focuses on the impacts on phototrophic and heterotrophic microorganisms in ricefield floodwater and soil.

Most of the earlier information on pesticide effects on nontarget soil microorganisms comes from observations in upland temperate soils (Wainright, 1978; Anderson, 1978). Anderson's review (1978) lists almost 500 references and tabulates 1,016 records on microbiological effects of pesticides, among which only eleven deal with rice soils. During the last two decades, more information on tropical wetlands has become available but emphasis has been on phototrophic microorganisms (Table 10.1).

The effects of pesticides on nitrogen transformations in soils were reviewed by Goring and Laskowski (1982) and Lal and Lal (1988); effects on nitrogen transformations in wetland soils were reviewed by Ray and Sethunathan (1988).

The literature dealing with the interactions between microalgae and pesticides published from 1946 to 1975 was reviewed by Butler (1977). The work published during this thirty-year period includes pesticide degradation, bioaccumulation, and bioassay; but the majority of the papers deal with pesticide toxicity tested *in vitro*. In their review on the influence of pesticides on soil algae McCann and Cullimore (1979) came to the similar conclusion that most information was from *in vitro* experiments mostly with herbicides. They pointed out that *in situ* studies were very scarce and results obtained by different workers for the same pesticide frequently conflicted. The literature dealing with the effects of pesticides on cyanobacteria (Padhy, 1985; Kumar, 1988) presents the same characteristics and most of the work concerns *in vitro* determination of lethal doses of pesticides on different strains (Padhy, 1985).

The first part of this review summarizes (1) the methodological aspects of the study of pesticide impacts on wetland soil microflora and places emphasis on the limitations of *in vitro* and small-scale experiments that have been the most frequent approach for such studies and (2) the factors that affect pesticide impact on ricefield microflora. The second part presents the analysis of quantitative data collected in 210 references originating from a larger database on microbiological

Table 10.1. Main Topics of the Bibliographic Data Base on Microbiological Impacts of Pesticides in Ricefields

| <i>Topics</i>                                                 | <i>Number of References</i> |
|---------------------------------------------------------------|-----------------------------|
| Methodological aspects including bioassays                    | 13                          |
| Decomposition and persistence of pesticides in rice soils     | 140                         |
| Effects on heterotrophic microbial populations and activities | 71                          |
| Effects on algae                                              | 272                         |
| Algicides and algal weeds                                     | 38                          |
| Effects on nontarget algae:                                   |                             |
| quantified effects on growth and activities                   | 149                         |
| Effects on nontarget algae: qualitative effects               | 29                          |
| Bioconcentration in algae                                     | 13                          |
| Effects on algal grazers                                      | 11                          |
| Effects on symbiotic cyanobacteria (Azolla)                   | 5                           |
| Adaptation and resistance of algae to pesticides              | 27                          |
| Miscellaneous                                                 | 26                          |
| Reviews including references to wetland soils                 | 18                          |
| Total                                                         | 527                         |

aspects of pesticide use in ricefields (Table 10.1). In the summary of recorded effects, emphasis is placed on field experiments.

Two annotated bibliographies on pesticide impacts on (1) ricefield algae and cyanobacteria and (2) nonphototrophic microorganisms of ricefield, are annexed to this review (Appendices D and E, respectively).

**10.2. Methodological Aspects of the Study of Pesticide Impacts on Soil and Water Microflora**

Methods used to study pesticide impacts on ricefield microflora include tests on cultures of microorganisms isolated from rice soils, small-scale experiments on soil in test tubes and beakers, and pot and field experiments.

*10.2.1. In Vitro Experiments*

Many studies of the effects of pesticides on soil microflora are laboratory experiments conducted with cultures of microorganism. This is especially characteristic

Table 10.2. Methods Used to Quantify Microbiological Impacts of Pesticides in Ricefields

| <i>Type of Experimental Design</i>   | <i>Algological Studies<br/>n° of Reports</i> | <i>Bacteriological Studies<br/>n° of Reports</i> |
|--------------------------------------|----------------------------------------------|--------------------------------------------------|
| Cultures of microorganisms           | 130                                          | 2                                                |
| Cultures of microorganisms with soil | 6                                            | 0                                                |
| Soil in test tubes or beakers        | 0                                            | 24                                               |
| Pot experiments                      | 3                                            | 21                                               |
| Field experiments                    | 10                                           | 14                                               |
| Method not available                 | <u>0</u>                                     | <u>10</u>                                        |
| Total                                | 149                                          | 71                                               |

of studies of soil algae and cyanobacteria for which most experiments have been performed in flasks with axenic or unialgal cultures of single species (Table 10.2).

Experiments with cultures of microorganisms can give an index of the sensitivity of the strains to pesticides, but it is difficult to draw general conclusions from such data because microorganisms of a same taxon often show different responses to the same pesticide (Hutber, Rogers, and Smith, 1979) and toxicity *in vitro* depends on the culture conditions (Kar and Singh, 1979a), the nutrient concentration (Kar and Singh, 1979b), and the initial size of the inoculum (Das, 1977). This is especially well demonstrated with cyanobacteria.

Marked differences in response of *Nostocaceae* (cyanobacteria) to pesticide *in vitro* were reported for Bavistin (carbendazin) for which tolerated concentrations were 300 ppm for *Westiellopsis* sp., 100 ppm for *Aulosira* sp., 100 ppm for *Nostoc* sp., 50 ppm for *Tolypothrix* sp. while 1 ppm was algicidal for *Calothrix* sp. (Gangawane, 1980). *Anabaena cylindrica* could tolerate concentrations of dichlone ten times higher than *Nostoc calcicola* and *Anacystis nidulans* (Kashyap and Gupta, 1981). Gadkari (1987) reported a two to ten times higher resistance of *Nostoc muscorum* to triazine herbicides as compared with *Anabaena cylindrica*. Even cyanobacteria of a same genus may show very different responses to the same pesticide (Venkataraman and Rajyalakshmi, 1971, 1972). Hutber, Rogers, and Smith (1979) found that 100 ppm of glyphosate was needed to reduce the growth of *Aphanocapsa* 6,714 by 50 percent while 2 ppm could achieve the same with *Aphanocapsa* 6,308. Chen (1986) found significant difference in the effects of various herbicides on N<sub>2</sub> fixation and photosynthetic activity by two strains of *Anabaena*.

The effect of culture conditions was demonstrated with carbofuran, which was more toxic to *Nostoc muscorum* under conditions reflecting or causing a low growth of the cyanobacteria (low inoculum, low light intensity, acidic pH) than

under conditions favorable for its growth (high inoculum, sufficient light, and acaaline pH) (Kar and Singh, 1979a). Carbofuran toxicity decreased with the level of nutrients in the medium (Kar and Singh, 1979b). The initial size of the inoculum had a significant role on the tolerance of *Anabaenopsis raciborskii*, *Anabaena aphanizomonoides*, *A. spiroides*, and *Microcystis flos-aquae* to 2,4-D and BHC (Das, 1977).

As pointed out by Hutber, Rogers, and Smith (1979), it is difficult to compare the results of different *in vitro* studies and to accurately assess the relative toxicity of pesticides on microorganisms because of (1) variations in the methods used to assess effects on growth, (2) the use in some cases of slow-growing organisms cultured under suboptimal conditions, and (3) the comparison of growth from a single sampling of cultures.

In addition toxicity tests were often performed in a way that hardly permits comparisons and extrapolations. Most *in vitro* experiments only indicate the concentration of pesticide used in the culture medium and not the recommended level for field application (RLFA). Assuming a floodwater depth of 5 to 10 cm and a homogeneous dissolution of pesticides—which is indeed quite far from the reality—the application of 1 kg of active ingredient (ai) per hectare would correspond to 1 to 2 ppm ai in water. Assuming a puddled layer of 15 cm with a bulk density of 0.5, the application of 1 kg ai/ha would correspond to about 1.33 ppm on soil dry weight basis. As in the field most pesticides are usually applied at dosages lower than 3 kg ai/ha, concentrations of 10 to several hundred ppm often tested in flask cultures appears to be used more to estimate a lethal level than to reflect field situation. They are of little value for drawing conclusions on impacts, except when no significant effect was recorded.

Results of *in vitro* trials can hardly be extrapolated to field conditions for several reasons summarized thereafter:

- Toxicity is likely to be higher in flask cultures than in the field. In soil, many factors interact with pesticides and modify their effect as compared with flask culture of a single organism and enhance pesticide degradation. These factors include biological degradation of the pesticide by the soil microflora, nonbiological degradation, photodecomposition, leaching, volatilization, and adsorption to the soil particles. For example, 5 ppm propanil prevented the growth of several cyanobacteria in flask cultures, but the same concentration did not produce any inhibition in the presence of unsterilized or sterilized soil and *in situ* (Ibrahim, 1972; Wright, Stainhope, and Downs, 1977).
- Toxicity depends on the initial microbial population and its nutrient status. These conditions are likely to markedly differ *in vitro* and *in situ*.
- In the field, toxicity depends on the method of pesticide application and water management.

- Toxicity depends on the formulation of the pesticide. *In vitro* experiments frequently test pure ingredients while, in the field, toxicity depends on the formulation. In particular some additives used in commercial formulations were shown to be detrimental to algae. The surfactant Renex 36 at a final concentration of 1.6 ppm in addition to the herbicide HOE-23408 at 2 ppm caused a much greater decrease of the soil algal population than when the herbicide was used alone (Linka, 1978). Similarly, the surfactant used in a commercial preparation of Picloram-D affected algal growth while the pesticide did not (Arvik, Willson, and Darlington, 1971).

Stratton, Burrell, Kurp, and Corke (1980) pointed out that acetone used to dissolve pesticides in *in vitro* tests may be responsible for a very significant part of the toxicities observed not only as direct effect but as synergistic effect between the solvent and the pesticide. The authors concluded that when 1 percent acetone was used to dissolve permethrin, the toxicity of the pesticide on *Anabaena cylindrica* was overestimated by twenty times.

- In the field toxicity depends on both the pesticide and the degradation products. A pesticide considered harmless in the laboratory may be dangerous when applied in the field due to the production of product(s) having different toxicity than the parent compound. The degradation product of propanil, 2,4-dichloroaniline, was less toxic than propanil towards the growth of *Gloeocapsa alpicola* whereas the degradation products of atrazine were more toxic than the parent compound toward *Anabaena inaequalis* (Stratton, 1984; Wright, Stainhope, and Downs, 1977). Metabolic products of aldrin, dieldrin, and endrin can be as inhibitory to algal growth than the parent compound (Batterton, Bousch, and Matsumura, 1971). 3,4-dichloroaniline, the primary product of propanil degradation, is less inhibitory than propanil, but at the concentration of propanil used in the field (12 ppm), the degradation product can still be inhibitory for some cyanobacteria (Wright, Stainhope, and Downs, 1977).

*In vitro* experiments are of limited practical value and should be limited to toxicity tests under standardized conditions in order to allow comparisons. A possible standardization could be the determination of the concentrations that would reduce by 50 percent the growth of reference organisms in exponential phase and the concentration that would totally inhibit their growth (Hutber, Rogers, and Smith, 1979).

### 10.2.2. Studies with Soil

Methods that can be used to determine the effects of herbicides on soil micro-organisms were summarized by Greaves et al. (1978) in a technical report of the

Weed Research Association. These methods are basically classical microbiological techniques, which include various soil analysis, the measurement of respiration and enzymatic activities (nitrogenase, phosphatase, dehydrogenase, urease, and cellulose decomposition), and bacterial counts. These methods can be used for any type of pesticide.

Most of the studies of the effect of pesticides on soil microflora have been performed as small-scale experiments in test tubes, beakers, and pots (Table 10.1). Such conditions might overestimate pesticide impact as compared with field situation because of (1) a longer persistence of pesticides due to the absence of rice plant and little variations of environmental conditions (temperature, redox, light, wind) and (2) a more even distribution pesticides and a better contact with microorganisms than *in situ*. The high pesticide concentrations sometimes used in such experiments may also overestimate pesticide efficiency because high concentrations seems to slow down pesticide degradation as shown with molinate (Deuel, Turner, Brown, and Price, 1978) and trifluralin, which degraded very slowly at 200 ppm and rapidly at 1.0 and 0.1 ppm (Parr and Smith, 1973).

Field trials have been mostly used for monitoring the persistence of pesticides and more rarely for record of bacterial populations and microbial activities. No long-term experiment monitoring the effect of pesticides on wetland soils microbiology has yet been reported in the literature.

Very few studies have compared *in situ* and *in vitro* effects of pesticides. In a study of 2,4-D and picloram, used in mixture in commercial herbicides, Arvik, Willson, and Darlington (1971) found no long-term effect of applications at the RLFA (0.3 to 1.1 kg ai/ha) on the composition of algal population *in situ*. Decrease in growth, determined *in vitro*, began at concentrations corresponding to the application of about 560 kg/ha of the herbicides.

### 10.2.3. *Microcosms and Models*

Several authors have develop small-scale models (microcosms) of ricefields or aquatic ecosystems to study or predict the bioaccumulation and dissipation of various pesticides applied to flooded ricefields (Chapter 5). Such methods offers an interesting alternative for detailed pesticide studies under controlled conditions, but they have not yet involved the study of the microbial components.

### 10.2.4. *Establishment of the Database Used in This Study*

Bibliographic references were collected according to the following criteria:

- All papers dealing with the effects of pesticides on microorganisms and microbial activities, and reporting studies in ricefields, with ricefield soil,

or with microbial, cyanobacteria or microalgae strains isolated from ricefields or known to be present in ricefields;

- Few papers of interest for methodological aspects or presenting data useful for comparison; and
- Bibliographic reviews including references on wetland soils.

Quantitative data on pesticide impacts were collected from this database, tabulated, and analyzed.

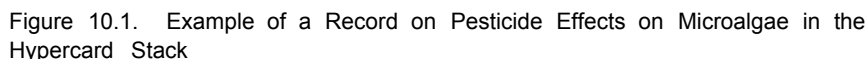
**10.2.4.1. Bias and Limitation of the Database.** Half of the papers of the database presents quantitative estimates of the effects of pesticides on microbial populations or their activities (Table 10.1). The literature on microalgae is more abundant (149 references) than that on other microorganisms (71 references) (Table 10.2) and deals mostly with herbicides (62 percent of the records) (Table 10.3) and cyanobacteria. The literature on other microorganisms deals mostly with insecticides (80 percent of the records). Moreover, most studies are small-scale laboratory experiments consisting of toxicity tests with algal cultures or test tube or flask experiments with a few grams of soil (Table 10.2).

Considering the numerous possible combinations to be tested (nature of pesticide  $\times$  pesticide concentration  $\times$  environmental conditions  $\times$  microorganisms or microbial activities), and the methodological limitations of the studies currently performed, the literature on microbiological impacts of pesticides in ricefields appears to be very fragmentary.

**10.2.4.2. Tabulation of the Results.** Data on cyanobacteria and microalgae collected in the database were primarily percentages of inhibition estimated by various measurements on cultures (dry weight, fresh weight, total nitrogen, chlorophyll content, etc.). They were tabulated for each pesticide in a especially designed Hypercard stack, using a grid combining a geometric scale of pesticide concentration and four levels of inhibition: none, <50 percent, 50 percent, >50 percent, and total inhibition (Figure 10.1). This tabulation allowed to identify results obtained at concentrations higher than the RLFA. Data obtained at concentrations corresponding to the RLFA were then entered in a spread sheet and summarized (Table 10.3).

Data for other microorganisms were bacterial counts and activity measurements, often performed at several time intervals after pesticide application. Inhibition, no effect, and enhancement were reported. For tabulating such data, each experiment was attributed a score of one within a five-case scale:

- All negative: the treatment was statistically lower than the control for all measurements;
- Negative trend: various effects were recorded, the balance was negative;



- No effect: no statistically significant difference between treatment and control;
- Positive trend: various effects were recorded, the balance was positive; and
- All positive: for all measurements the treatment was statistically higher than the control.

Results were then tabulated in a spreadsheet containing for each record: the name of the pesticide, its nature (herbicide, insecticide), the range of the RLFA, the dose(s)/concentration(s) used for the experiment, the type of experimental design (*in situ*, pot experiment, flask experiment), the population/activity measured, the environment (soil, rhizosphere), the duration of the experiment, the dates of the observations in days after pesticide application, and the effect at the RLFA (five columns) and at concentrations higher than the RLFA (five columns).



Table 10.3. Summary of Data on the Effect of 109 Pesticides on Ricefield Microalgae at Concentrations Corresponding to the Recommended Level for Field Application

| Nature of the Data                        | Number of Data | Percent of Data Corresponding to Each of the Above Five Levels of Inhibition |       |     |       |      |
|-------------------------------------------|----------------|------------------------------------------------------------------------------|-------|-----|-------|------|
|                                           |                | None                                                                         | < 50% | 50% | > 50% | 100% |
| All data                                  | 407            | 39                                                                           | 19    | 26  | 2     | 14   |
| All data <i>in situ</i> or with soil      | 39             | 62                                                                           | 8     | 3   | 3     | 26   |
| Algicides (3 tested)                      | 33             | 3                                                                            | 0     | 67  | 0     | 30   |
| Fungicides (22 tested) <sup>a</sup>       | 30             | 40                                                                           | 10    | 7   | 0     | 43   |
| Herbicides (57 tested)                    | 252            | 33                                                                           | 25    | 28  | 2     | 12   |
| Herbicides, <i>in situ</i> or with soil   | 24             | 58                                                                           | 8     | 4   | 4     | 25   |
| Insecticides (28 tested)                  | 97             | 67                                                                           | 11    | 14  | 3     | 4    |
| Insecticides, <i>in situ</i> or with soil | 10             | 90                                                                           | 10    | 0   | 0     | 0    |

Note: Data on microalgae and cyanobacteria presented in this table and the following ones are from: Adhikari (1989), Ahmad and Venkataraman (1973), Arvik, Willson, and Darlington (1971), Arvik, Hyzak, and Zimdahl (1973), Battino-Viterbo, Minervini-Ferrante, and Bisiach (1973), Bisiach (1971, 1972), Bongale (1985), Cameron and Julian (1984), Chen Pei Chung (1986), Das and Singh (1977a, b), Das and Singh (1978), Das and Singh (1979), DaSilva, Henriksson, and Henriksson (1975), Dunigan and Hill (1978), Dunigan, Hutchinson, and Hill (1979), El-Haddad (1984), El-Sawy et al. (1984), Fritz-Sheridan (1982), Gangawane (1979, 1980), Gangawane and Kulkarni (1979), Gangawane and Saler (1979), Gangawane, Chaporkar, and Khalil (1982), Ghosh and Saha (1988), Gibson (1972), Gupta and Saxena (1974), Hamdi, El Nawawy, and Tewfik (1970), Holst, Yopp, and Kapusta (1982), Huter, Rogers, and Smith (1979), Ibrahim (1972), Inger (1970), Ishizawa and Matsuguchi (1966), Kar and Singh (1978, 1979a, 1979b, 1979c), Kashyap and Gupta (1981), Kashyap and Pandey (1982), Kaushik and Venkataraman (1983), Khalil, Chaporkar, and Gangawane (1980), Kumar and Singh (1981), Singh, Tiwari, and Singh (1986), Mallison and Cannon (1984), Maule and Wright (1984), Megharaj, Venkateswarlu, and Rao (1988a, 1988b), Megharaj, Venkateswarlu, and Rao (1989a, 1989b), Mehta and Hawxby (1979), Minervini-Ferrante, Battino-Viterbo, and Bisiach (1974), Mukheji and Laha (1979), Mukherji and Ray (1966), Mukherji and Sengupta (1964), Singh (1973, 1974), Pande, Rekha Sarkar, and Krishnam-Oorthi (1981), Pandey (1985), Pandey and Kashyap (1986), Pandey and Tiwari (1986), Patnaik and Ramachandran (1976), Pillay and Tchan (1972), Singh, Singh, and Singh (1983), Singh, Rana, and Carg (1986), Raghu and MacRae (1967), Saha, Mandal, Sannigarahi, and Brandhopadhya (1982), Saha, Sannigarahi, Brandhopadhya, and Mandal (1984), Sardespande and Goyal (1982), Satapathy and Singh (1987), Schauburger and Wildman (1977), Sharma and Gaur (1980), Shivaram and Shetty (1988), Singh and Singh (1988), V.P. Singh et al. (1978), Sinha, Pal, and Trial (1986), Smith, Flinchum, and Seaman (1977), Srinivasan (1981), Srinivasan and Ponnuswami (1978), Stratton and Corke (1981), Subramanian (1982), Subramanian and Shanmugasundaram (1986), Theivendirajah and Jeyaseelan (1981), Tiwari, Pandey, and Mishra (1981), Tiwari, Pandey, Mishra, and Srivastava (1982), Tiwari, Pandey, and Misra (1984), Tuba Hawxby, and Mehta (1981), Vaishampayan (1985), Vaishampayan and Prasad (1982), Vaishampayan, Singh, and Singh (1978), Vance and Drummond (1969), Venkataraman and Rajylakswami (1971), Wegener, Aldag, and Meyer (1985), Wright and Maule (1982), Zargar and Dar (1990).

a. Several fungicides act also as algicides.

When no statistical analysis was performed by the authors, which was most often observed with bacterial enumerations, we have assumed that data were of lognormal distribution and considered as significantly different the results at least three times higher or lower than the control (Roger, Jimenez, and Santiago-Ardales 1991).

### **10.3. Factors Affecting Pesticide Toxicity on Soil Microorganisms**

#### **10.3.1. Soil Properties**

Little information is available on soil properties that affect pesticide impacts on ricefield microorganisms. The few studies conducted with several soils report some differences in pesticide impacts. In particular the response of  $N_2$ -fixing organisms to benomyl, carbofuran and gamma-BHC varied with the soil type (Rajaramamohan Rao, 1980). Mephosfolan had positive or negative effects on the populations of bacteria and actinomycetes depending on the soil studied (Sivaraj and Venugopal, 1979). However, data are too scarce to draw general conclusions. Observations with cultures of cyanobacteria allow some hypothesis. As a general trend, it is usually found that pesticide toxicity to cyanobacteria increases when the growth medium is adjusted to acidic range. It is probable that cyanobacteria, which prefer alkaline environments, are less tolerant to pesticides in acidic than in neutral or alkaline soils. This has been observed in liquid cultures (Das, 1977) but not confirmed by studies in soil. *Anacystis nidulans* was found to tolerate 1 percent CINa and DDT at 0.8 ppm separately, but growth was inhibited in the presence of both compounds (Batterton, Bousch, and Matsumura, 1972). This aspect might have implications in brackish rice soils.

#### **10.3.2. Water Management and Method of Pesticide Application**

A faster pesticide dilution in wetland than in upland soils might be expected, with variations depending upon solubility and the surfactants used. Megharaj, Venkateswarlu, and Rao (1988b) in laboratory experiments observed that carbofuran applied at 5 kg/ha had no effect in flooded soil but caused a transitory decrease in total algal population at ten days in nonflooded soil that disappeared at twenty days. The relations between floodwater management and methods of pesticide application might affect the toxicity of the pesticides with regard to dilution and movements in soil. Water depth is taken into account for algicide

application (Mukherji, 1968) but little information is available on this aspect for other pesticides.

Rao, Pasalu, and Rao (1983) found significant differences in the effect of the same pesticide when applied in the floodwater, incorporated into the soil, or used for dipping rice seedling. In particular HCH incorporated in the soil caused an initial inhibition up to seventy days of rhizosphere soil nitrogenase, while it was stimulating throughout the rice growing period when applied in floodwater. Pentachlorophenol incorporated in soil with lime stimulated  $N_2$ -fixing cyanobacteria; but if broadcast in floodwater, even at low levels, it was depressive with a long residual effect (Ishizawa and Matsuguchi, 1966).

### **10.3.3. *Synergistic Effects and Interactions with Other Agrochemicals***

Pesticides in combination may interact with each other and alter their respective toxicity on microorganisms (Arvik, Willson, and Darlington, 1971; Chinnaswamy and Patel, 1983; Stratton, 1984). Synergistic stimulatory effects of pesticides on  $N_2$  fixation were reported for combinations of carbofuran with benomyl, nitrofen, and gamma-HCH. On the contrary, diazinon slightly retarded the stimulatory effect of benomyl and carbofuran (Nayak and Rajaramamohan Rao, 1982). Ray, Ramakrishna, and Sethunathan (1980) reported a synergistic increase in the inhibition of nitrification by a combined application of HCH and carbofuran.

Repeated application of the same pesticide has been reported to enhance the growth of the related specific decomposing microorganisms and cause the rapid inactivation of the pesticide. This aspect is summarized by Roger and Bhuiyan (Chapter 5).

Nitrogen fertilizer is known to inhibit  $N_2$ -fixation at different levels. Concomitant use of N fertilizer and pesticides in ricefields may affect pesticide toxicity to  $N_2$ -fixing organisms. In the case of cyanobacteria, carbofuran toxicity was higher under  $N_2$  fixing conditions than under heterotrophic growth on nitrate (Kashyap and Gupta, 1981; Kashyap and Pandey, 1982; Pandey, Srivastava, and Tiwari, 1984).

## **10.4. Impacts on Photosynthetic Microorganisms**

### **10.4.1. *Effects on Populations of Microalgae and Cyanobacteria***

Pesticides have three major effects on ricefield algae and cyanobacteria: (1) a selective toxicity that affects preferentially green algae and thus promote

cyanobacteria growth, (2) a short-term promoting effect of insecticides on microalgae, due to a temporary decrease of invertebrates that graze on algae, (3) a selective effect of insecticides on cyanobacteria by causing a recruitment of algal grazers, which results in the dominance of strains forming mucilaginous macrocolonies resistant to grazing. There are also reports indicating no significant effects of pesticides applied at RLFA on algal flora in the presence of soil (Megharaj, Venkateswarlu, and Rao, 1988a, 1988b).

The database tabulates 1,045 records of effects on algae. However 638 tests were performed at concentrations higher than that corresponding to the RLFA, probably because most studies were conducted *in vitro* (96 percent) and aimed at establishing LC<sub>50</sub> or the lethal concentration for the strains rather than testing the possible effects *in situ*. In this section, we analyze the 407 records of pesticide effects obtained at concentrations corresponding to the RLFA (Table 10.3).

An absence of effect of pesticides was reported in 39 percent of the total number of records but only in 62 percent of the records obtained *in situ* or in the presence of soil. This confirms that pesticide effects are more marked in *vitro* than *in situ*. However, most data were obtained *in vitro* and this bias must be kept in mind in the following discussion.

**10.4.1.1. Effects of Algicides and Fungicides.** Many fungicides for use in ricefield were tested primarily as algicides and are therefore considered together with algicides. Algicides are usually applied in ricefields to control macrophytic (*Chara* spp., *Nitella* spp.) or mat-forming algae (*Spirogyra* spp., *Hydrodictyon* spp.). Microalgae are usually not considered as weeds. Several reports indicate a preferential inhibitory effect of algicides on green algae which results in the promotion of cyanobacteria growth. This was observed with symetryne (Yamagishi and Hashizume, 1974) and algaedyn (Almazan and Robles, 1956). This may explain why only 30 to 40 percent of total inhibition were recorded with algicides and fungicides.

**10.4.1.2. Effects of Insecticides.** Insecticides had a low impact on tested cyanobacteria and algae, as shown by the high percentage of records indicating no inhibition in the whole database (67 percent) and *in situ* (90 percent) (Table 10.3).

A preferential inhibitory effect of insecticides on green algae, which resulted in the promotion of cyanobacteria growth, was observed with BHC (Ishizawa and Matsuguchi, 1966; Raghu and MacRae, 1967a, 1967b) and PCP (Watanabe, 1977). Simultaneously, insecticides inhibited invertebrates that feed on algae (grazers), thus promoting furthermore BGA and photodependant biological N<sub>2</sub> fixation. This was observed with parathion applied at 1 to 5 ppm in the flood-water (Hirano, Shiraishi, and Nakano, 1955), ethyl parathion applied at 0.2 ppm (Osa-Afiana and Alexander, 1981) phorate (Srinivasan and Emayavaramban,

1977), and carbofuran (Tirol, Santiago, and Watanabe, 1981). Similarly parathion controlled grazers in a lake in the United States, and favored *Anabaena* growth (Cook and Gonner, 1963).

However, insecticide application did not invariably increase photodependant BNF. Some inhibitory effect was reported for PCP *in situ* (Ishizawa and Matsuguchi, 1966).

Also, in the long term, insecticide use might become detrimental to N<sub>2</sub>-fixing cyanobacteria by decreasing the diversity of aquatic invertebrates and causing proliferation of algal grazers. The relative acute lethal toxicity of carbofuran to the ostracod *Heterocypis luzonensis* was 2.4 µg/ml and that of lindane was 56.0 µg/ml (Grant, Eagan, and Alexander, 1983). Such resistance to conventional pesticides allows large densities of ostracods to develop after pesticide application (5,000 to 15,000/sq m), particularly as the natural predators succumb first. Ostracod populations may cause the disappearance of algal blooms in a few days. Takamura and Yasuno (1986) reported the proliferation of chironomids and ostracods in herbicide and insecticide-treated fields, while the number of their natural predators decreased. Microalgae decreased in herbicide-treated plots and did not increase in insecticide-treated plots probably because of grazing.

**10.4.1.3. Effects of Herbicides.** Algae, as photosynthetic organisms, should be expected to be more sensitive than other microorganisms to herbicides, especially the photosynthetic inhibitors. Among pesticides not aiming at algal control, herbicides appears to be most detrimental to algae, causing partial or total inhibition in 67 percent of the *in vitro* tests and in 42 percent of the tests performed *in situ* or in the presence of soil (Table 10.3). Several unicellular eukaryotic algae most common in ricefields (*Chlorella*, *Chlamydomonas*, *Euglena*) have been shown to be sensitive to photosynthetic inhibitors herbicides (Arvik, Hyzak, and Zimdahl, 1973). Herbicides can inhibit cyanobacteria and photodependant BNF, as shown with PCP—a pesticide that is used as insecticide and herbicide—Ishizawa and Matsuguchi, 1966) and several formulations used in ricefields (Srinivasan and Ponnuswami, 1978). Some herbicides seem to affect specifically the N<sub>2</sub>-fixing ability of cyanobacteria as indicated by an inhibition observed in N-free medium but not in the presence of inorganic N. This was observed with dichlone (fungicide/algicide) (Kashyap and Gupta, 1981) and machete (butachlor) (Kashyap and Pandey, 1982).

#### 10.4.2. Effects on Photodependant Biological N<sub>2</sub> Fixation

Raghu and MacRae (1967a, 1967b) were probably the first to report marked stimulation of growth of indigenous cyanobacteria and nitrogen fixation on the

application of gamma-HCH in submerged paddy soils even at 5 kg/ha. This stimulation was attributed to the toxic action of gamma-HCH on algal grazers. Similarly, increased nitrogenase activity in paddy water treated with carbofuran (6 kg ai/ha) was attributed to inhibition of micro-crustaceans and consequent build-up of N<sub>2</sub>-fixing cyanobacteria (Tirol, Santiago, and Watanabe, 1981).

However, pesticide application do not invariably increase BNF by cyanobacteria. Insecticide HCH at 50 µg/g (Ishizawa and Matsuguchi, 1966), and the herbicides CNP (2,4,6-trichlorophenyl4-nitro-phenyl ether) (Matsuguchi, 1979) and propanil (Habte and Alexander, 1980) inhibited the nitrogenase activity of cyanobacteria in a flooded soil. Some pesticides seem to affect specifically the N<sub>2</sub>-fixing ability of cyanobacteria as indicated by the observation that the inhibitory effect of dichlone (Kashyap and Gupta, 1981) and butachlor (Kashyap and Pandey, 1982) on N<sub>2</sub>-fixing strains growing in N-free medium was markedly decreased or reversed by inorganic N sources. Whereas herbicides seem to be the most detrimental pesticides for photodependant biological N<sub>2</sub> fixation, several species of cyanobacteria tolerated levels (100 to 500 ppm) of 2,4-D much higher than RLFA suggesting that this herbicide might be compatible with cultural practices aiming at promoting cyanobacteria growth as biofertilizer (Venkataraman and Rajyalakshmi, 1971, 1972).

In the numerous experiments dealing with inoculation of ricefields with N<sub>2</sub>-fixing strains of cyanobacteria (Roger, 1991) almost no field trials have tested the interaction between pesticides and algal inoculation. Kerni, Shant, Singh, and Gupta (1983) and Kerni, Shant, Gupta, and Singh (1984) concluded to the absence of effect of butachlor applied at 5–30 kg/ha in inoculated plots. El-Sawy et al. (1984) in a pot experiment tested the interaction between cyanobacteria inoculation and four herbicides by measuring plant characteristics and soil nitrogen at 40 days after transplanting (DAT). They found that when algal inoculation was effective, herbicide application had most often no effect or a positive effect over the inoculated control (14 of 16 cases). Negative effects (two of 16 cases) were observed with propanil.

Information on the effects of pesticides on BNF by N<sub>2</sub>-fixing cyanobacteria symbiotic of *Azolla* is limited. Insecticides, by decreasing pest incidence, usually favor *Azolla* growth (Satapathy and Singh, 1987; Singh and Singh, 1988). Herbicides have more often detrimental effect. Holst, Yopp, and Kapusta (1982) tested *in vitro* the effect of fifteen herbicides on growth and N<sub>2</sub> fixation of *Azolla mexicana*. Biprydiliun and phenolic herbicides were the most detrimental, causing up to a 75 percent reduction in N<sub>2</sub> fixation and nitrate reduction at 0.1 ppm. Chloramben and benomyl at 10 ppm caused an 84 to 99 percent reduction in N<sub>2</sub> fixation without affecting nitrate reduction or growth. Simazine at 10 ppm stimulated nitrate reduction 20 fold, causing a 99 percent reduction in N<sub>2</sub> fixation. Growth and N<sub>2</sub> fixation were reduced by other benzoic, triazine, dinitroaniline,

and urea herbicides tested at concentrations between 0.1 and 10 ppm. Naptalam was the only pesticide tested that had no effect on growth or  $N_2$  fixation at 10 ppm. *In situ*, preemergence herbicide applied about one week before *Azolla* inoculation had only limited effects on *Azolla*, while postemergence herbicides were more detrimental (Singh and Singh, 1988).

#### 10.4.3. *Bioconcentration of Pesticides in Microalgae and Cyanobacteria*

Microalgae and cyanobacteria, the base constituents of the aquatic food web in wetland ricefields, have a high surface area/volume ratio, which give them a significant potential for sorption of, and reaction with pesticides (Wright, 1978). They can concentrate pesticide manyfold and, in general, are more resistant to their toxic effects than the food web's high members (Vance and Drummond, 1969). Little field data is available on bioconcentration of pesticide by phototrophic microorganisms in ricefields, but data from laboratory experiments and studies in microcosms and freshwater ecosystems, demonstrate that microalgae and cyanobacteria in ricefields may play an important role in accumulating pesticides that become available to bioconcentration through the food web.

For example, cyanobacteria concentrated 100 to 250 times chlorinated pesticides introduced at a level of 1 mg/L in the culture medium (Vance and Drummond, 1969). Maximum bioaccumulation ratio of fenitrothion ranged from 44 to 105 in living cells and from 100 to 1,810 in dead cells of *Chlorella vulgaris*, *Nitzschia closterium*, and *Anabaena flos-aquae*. Corresponding values for DDT were 420 to 82,000 and 1,000 to 210,000 (Kikuchi et al., 1984).

This aspect is important when considering the ricefield ecosystem as a possible environment for aquaculture (rice-fish, rice-shrimp).

#### 10.4.4. *Results from Field Experiments*

Most field studies on microalgae or cyanobacteria conducted in the field deal on either algicides used to control algal blooms of microalgae (Dunigan and Hill, 1978; Dunigan, Hutchinson, and Hill, 1979) or the application of synthetic insecticides (Srinivasan, 1981; Grant, Eagan, and Alexander, 1983; Grant, Roger, and Watanabe, 1986) or insecticides of plant origin (Watanabe et al., 1981; Grant, Eagan, and Alexander, 1983; Grant, Seegers, and Watanabe, 1984) to promote photodependant biological  $N_2$ -fixation by controlling cyanobacteria grazers.

Experiments to assess the effect on nontarget algae and cyanobacteria deal mostly with herbicide application. In tropical countries little impact of herbicide was reported. Arvik, Willson, and Darlington (1971) found no change in the

composition of the algal flora over an 18-month period after the application of a 1:4 commercial mixture of 4-amino- 3,5,6-trichloropicolinic acid (picloram) and (2,4-dichlorophenoxy) acetic acid (2,4-D) at RLFA. Srinivasan and Ponnuswami (1978) found either no significant effect or a slight inhibitory effect on cyanobacteria of seven herbicides applied at RLFA. Singh, Rana, and Carg (1986) studying the effect of butachlor, thiobencarb, and 2,4-D on  $N_2$ -fixing cyanobacteria found that the recommended rates of herbicide did not result in major changes in the composition of the algal population. All herbicides increased the proportion of *Nostoc*, while propanil reduced the proportion of *Anabaena*.

In temperate countries, some inhibitory effect of herbicides was reported. In Japanese ricefields, benthic algae decreased with applications of herbicide but did not increase markedly in fields treated with insecticide (Takamura and Yasuno, 1986). In Italian ricefields, heterocystous and nonheterocystous cyanobacteria, and microalgae were differently affected by the repeated use of simazine (4 kg/ha), the first being more severely affected. The herbicide produced a reduction in the species diversity, which was very evident in the case of heterocystous cyanobacteria (Tomaselli, Giovannetti, and Materassi, 1987).

Resistance to biocides is a common phenomenon. Cyanobacteria can be adapted to increased concentrations of pesticides (Sharma and Gaur, 1981). When several strains of algae are tested for sensitivity to pesticides, strains resistant to field levels are usually identified (Gadkari, 1987). Spontaneous mutants resistant to pesticides (monuron, blitox) have been isolated (Vaishampayan, 1984, 1985; Vaishampayan and Prasad, 1982). The study of various classes of herbicides by Hawxby, Tubea, Ownby, and Basler (1977) showed that s-triazines and substituted ureas could alter phytoplankton composition by selective inhibition of certain species. As sensitivity to a given pesticide may vary between quite large limits among algal strains, pesticide application might cause shifts in dominant strains within the algal/cyanobacterial community rather than a decrease of the whole algal biomass.

## **10.5. Impacts on Nonphotosynthetic Microorganisms and Their Activities**

### **10.5.1. General Trends**

Contrary to experiments with microalgae and cyanobacteria, most tests on nonphotosynthetic microflora and its activities were performed in the presence of soil, either in small-scale experiments (51 percent of the data) or *in situ* (47 percent of the data) (Table 10.4). Also, most experiments were performed at concentrations corresponding to the RLFA. The database tabulates 606 records obtained at such concentrations. About 60 percent of the records deal with



Table 10.4. Summary of *in situ* and *in vitro* Data on Microbiological Effects of Pesticides in Ricefields at Concentrations Corresponding to the Recommended Level for Field Application: Methodological Aspects

| Groups                                     | Number of Data | Percent of Data for Each Effect <sup>a</sup> |                |           |                |             |
|--------------------------------------------|----------------|----------------------------------------------|----------------|-----------|----------------|-------------|
|                                            |                | All Negative                                 | Negative Trend | No Effect | Positive Trend | AN Positive |
| All data                                   | 606 (100%)     | 8                                            | 12             | 60        | 11             | 9           |
| Summary by experimental design (606 data): |                |                                              |                |           |                |             |
| Field experiments                          | 309 (51%)      | 5                                            | 17             | 73        | 4              | 2           |
| Pot and flask expts.                       | 283 (47%)      | 10                                           | 8              | 46        | 18             | 19          |
| Summary by environment (590 data):         |                |                                              |                |           |                |             |
| Soil                                       | 347 (59%)      | 7                                            | 12             | 52        | 16             | 14          |
| Rhizosphere                                | 243 (41%)      | 8                                            | 13             | 70        | 5              | 5           |
| Summary by pesticide group (600 data):     |                |                                              |                |           |                |             |
| Fungicides                                 | 58 (10%)       | 5                                            | 0              | 50        | 24             | 21          |
| Herbicides                                 | 102 (17%)      | 13                                           | 23             | 30        | 21             | 14          |
| Insecticides                               | 440 (73%)      | 6                                            | 11             | 68        | 7              | 8           |

Note: Data on nonphotosynthetic microorganisms presented in this table and the following ones are from: Akhtar, Solangi, and Baig (1986), Azad and Khan (1968), Baruah and Mishra, (1986), Chen Ching Chao (1983), Charyulu, Ramakrishna, and Rao (1980), Chen (1980), Chendrayan and Sethunathan (1980), De and Mukhopadhyay (1971), Endo, Kusaka, Tan, and Sakai (1982), Furusaka (1978), Gowda, Rao, and Sethunathan (1977), Jayachandran and Chandramohan (1977), Jena and Rajaramamohan Rao (1987), Kandasamy et al. (1975), MacRae, Raghu, and Castro (1967), Mahapatra and Rao (1981), Mandal, Bandyopadhyay, Bandyopadhyay, and Maity (1987), Mitsui, Watanabe, Honma, and Honda (1964), Nair, Ramakrishnan, and Sithanatham (1974), Nayak and Rajaramamohan Rao (1980, 1982), Nishio and Kusano (1978), Palaniappan and Balasubramanian (1985), Patnaik, Panda, and Dash (1986), Purushothman, Venkataraman, and Kasirajan (1976), Raghu and MacRae (1967a, 1967b), Ramakrishna, Rao, and Sethunathan (1978), Ramakrishna, Gowda, and Sethunathan (1979), Ramakrishna and Sethunathan (1982), Rao, Pasalu, and Rajaramamohan Rao (1983), Rao Prasad, and Rajaramamohan Rao (1984), Ray, Ramakrishna, and Sethunathan (1980), Ray and Sethunathan (1980), Roy, Sinha, and Mukherjee (1975), Russo (1970), Sathasivan, Palaniappan, and Balasubramanian (1982), Sato (1987), Sethunathan and MacRae (1969), Singh, Tiwari, and Singh (1986), Sivaraj and Venugopal (1979), Sivasithamparam (1970), Tirol, Santiago, and Watanabe (1981), Turner (1979), Yeomans and Bremner (1985).

a. See text for definition of effects.

populations or activities in the bulk of soil and 40 percent deal with the rhizosphere. Data suffer from a strong bias in the nature of pesticides tested, 73 percent of the records being on insecticides (Table 10.4).

On an average, 20 percent of the trials reported a negative effect of pesticide application, no significant effect was observed in 60 percent of the cases, and positive effects were recorded in 20 percent of the cases.

Table 10.5. Summary of *in situ* and *in vitro* Data on Microbiological Effects of Pesticides in Ricefields at Concentrations Corresponding to the Recommended Level for Field Application: Organismal Aspects

| Groups                                                                            | Number of Data | Percent of Data for Each Effect <sup>a</sup> |                |           |                |              |
|-----------------------------------------------------------------------------------|----------------|----------------------------------------------|----------------|-----------|----------------|--------------|
|                                                                                   |                | All Negative                                 | Negative Trend | No Effect | Positive Trend | All Positive |
| All data                                                                          | 606(100%)      | 8                                            | 12             | 60        | 11             | 9            |
| Summary for microbial counts (249 data, 51 % of all data):                        |                |                                              |                |           |                |              |
| All microbial counts                                                              | 249(100%)      | 10                                           | 10             | 58        | 13             | 9            |
| Actinomycetes                                                                     | 37 (15%)       | 3                                            | 19             | 62        | 8              | 8            |
| Bacteria                                                                          | 175 (70%)      | 13                                           | 9              | 52        | 15             | 11           |
| Fungi                                                                             | 37 (15%)       | 5                                            | 5              | 81        | 8              | 0            |
| Summary for measurements other than microbial counts (357 data, 47% of all data): |                |                                              |                |           |                |              |
| All measurements                                                                  | 357 (100%)     | 6                                            | 14             | 61        | 10             | 10           |
| Microbial activities                                                              | 225 (63%)      | 8                                            | 18             | 46        | 13             | 15           |
| Enzymatic activities                                                              | 123 (34%)      | 0                                            | 7              | 93        | 1              | 0            |
| Others                                                                            | 9 (3%)         |                                              |                |           |                |              |

a. See text for definition of effects.

Experiments *in situ* showed a higher percentage of no significant effects (73 percent) than small-scale experiments (46 percent), confirming that the last ones may overestimate pesticide effects. Extreme effects (all negative or all positive) were also more frequent in small-scale trials than *in situ*.

Pesticide effects appeared to be more marked in the bulk of soil (no effect: 52 percent) than in the rhizosphere (no effect: 70 percent), which is a more active and probably more resilient microenvironment than the nonrhizospheric soil. Herbicides affected more often the microflora or its activities (no effect: 30 percent) than fungicides (no effect: 50 percent) and insecticides (no effect: 68 percent).

The summary of effects according to counts of microbial populations and other types of measurements (Table 10.5) shows that, on an average, populations of microorganisms were less affected by pesticides (58 percent of no effects) than microbial activities (46 percent of no effects).

Within microbial populations, fungi (80 percent of no effect) and actinomycetes (62 percent of no effect) were less sensitive to pesticides than bacteria (52 percent of no effect). As the relative abundance of actinomycetes and fungi is much lower in wetland soils than in upland soils, the imbalance of the data with regard to their distribution among microbial groups (70 percent of data on bacteria) reflects the field situation.

Microbial activities were more affected than enzymatic activities. Among

Table 10.6. Summary of *in situ* and *in vitro* Data on Microbiological Effects of Pesticides in Ricefields at Concentrations Corresponding to the Recommended Level for Field Application: Nitrogen Cycle

| Groups                                                                                   | Number of Data | Percent of Data for Each Effect <sup>a</sup> |                |           |                |              |
|------------------------------------------------------------------------------------------|----------------|----------------------------------------------|----------------|-----------|----------------|--------------|
|                                                                                          |                | All Negative                                 | Negative Trend | No Effect | Positive Trend | All Positive |
| All data                                                                                 | 606 (100%)     | 8                                            | 12             | 60        | 11             | 9            |
| Data on N cycle 302 (50% of all data)                                                    |                | 8                                            | 15             | 48        | 16             | 13           |
| Summary for BNF (176 data, 29% of all data, 58% of data on N cycle):                     |                |                                              |                |           |                |              |
| All data on BNF                                                                          | 176 (100%)     | 2                                            | 23             | 31        | 26             | 19           |
| Bacterial counts                                                                         | 69 (39%)       | 4                                            | 3              | 52        | 23             | 17           |
| BNF measurements                                                                         | 107 (61%)      | 0                                            | 36             | 18        | 27             | 20           |
| In bulk of soil                                                                          | 95 (54%)       | 1                                            | 12             | 25        | 37             | 25           |
| In rhizosphere                                                                           | 81 (46%)       | 2                                            | 36             | 38        | 12             | 11           |
| Fungicides                                                                               | 25 (14%)       | 0                                            | 0              | 20        | 52             | 28           |
| Herbicides                                                                               | 26 (15%)       | 0                                            | 23             | 23        | 35             | 19           |
| Insecticides                                                                             | 125 (71%)      | 2                                            | 27             | 35        | 18             | 17           |
| Summary of other aspects of N cycle (126 data, 21% of all data, 42% of data on N cycle): |                |                                              |                |           |                |              |
| All other aspects                                                                        | 126 (100%)     | 16                                           | 6              | 71        | 3              | 5            |
| Nitrification                                                                            | 54 (43%)       | 30                                           | 4              | 61        | 0              | 6            |
| Denitrification                                                                          | 47 (37%)       | 6                                            | 4              | 87        | 2              | 0            |
| Others                                                                                   | 25 (20%)       | 4                                            | 12             | 60        | 12             | 12           |

a. See text for definition of effects.

123 tests on ten soil enzymes, 93 percent showed no effect of pesticide application. Only b -glucosidase reacted negatively to pesticide application (Purushothaman, Venkataraman, and Kasirajan, 1976).

Half of the records of the database deal with N cycle. About 60 percent of the data on N cycle concern BNF and 30 percent concern nitrification and denitrification. Data on other aspects are not numerous enough to allow general conclusions (Table 10.6).

### 10.5.2. Effects on Heterotrophic Biological N<sub>2</sub> Fixation

N<sub>2</sub>-fixing microflora and BNF were more affected by pesticides (no effect: 31 percent) than other populations and activities of the N cycle (no effect: 71 percent). The low percentage of nonsignificant effects on BNF was mostly due to a higher number of positive effects (45 percent), observed indiscriminately

with fungicides, herbicides, and insecticides. Data on BNF confirm some of the observations made with the whole database—namely a higher sensitivity of the nonrhizospheric microflora to pesticides than the rhizospheric microflora, and a more marked impact of fungicides and herbicides than that of insecticides. A noticeable difference, as compared with the whole database, is that populations were much less affected (no effect: 52 percent) than the activities (no effect: 18 percent).

With 25 percent of negative effects and 45 percent of positive effects, BNF seems to be quite versatile in its response to pesticides applied at concentrations corresponding to the RLFA. Nayak and Rajaramamohan Rao (1980), using benomyl, carbofuran and gamma-BHC applied at the RLFA (5 ppm) in five soils and  $^{15}\text{N}$  tracer techniques under laboratory conditions (5g soil samples), found both positive and negative effects on  $\text{N}_2$  fixation. Most often, a positive effect was observed, but a single pesticide could exhibit negative or positive effect depending on the soil type. Also Rao, Pasalu, and Rajaramamohan Rao (1983) reported variables effects of the same pesticide depending on the method of application.

### 10.5.3. *Effects on Nitrification-Denitrification*

Nitrification was not affected by pesticides in about 60 percent of the cases. This value is similar to the average of the database. However, negative effects were much more frequent (34 percent of the cases) than positive effects (6 percent of the cases). Nitrification inhibition cannot be considered detrimental because it reduces losses from nitrogen fertilizer. In fact the identification of efficient and economically feasible nitrification inhibitors has been an important objective of the research on the microbial management of ricefields (Roger, Zimmerman and Lumpkin, 1993).

Denitrification was not affected by pesticides in 87 percent of the cases. This is probably because the denitrifying microflora, being complex and very versatile, is able to metabolize or to resist a wide range of substrates. As a result, high pesticide levels are needed to inhibit denitrification.

Mitsui, Watanabe, Honma, and Honda (1964), testing the effect of eight dithiocarbamate pesticides in a rice soil, found that 20 ppm Vapam (metham) or 100 ppm of the other pesticides was required to significantly decrease denitrification at two and five days after pesticide application. Such concentrations are higher than the RLFA.

### 10.5.4. *Results from Field Experiments*

Most field studies dealing with microflora present no statistical analyses of the data, but results of microbial enumerations after pesticide application often

indicate either an absence of effect or minor effects (Patnaik, Panda, and Dash, 1986).

Both positive and negative effects of pesticides have been observed. A positive effect of insecticide gamma-BHC on  $N_2$  fixation and populations of anaerobic, phosphate-dissolving bacteria was reported by Raghu and MacRae (1967a, 1967b). A decrease in microbial population was reported after the application of insecticides diazinon, cytolane, carbofuran, carbaryl + lindane, quinalphos, and Dursban at RLFA whereas fungal populations were not affected (Purushothaman, Venkataraman, and Kasirajan, 1976). Total count of benthic bacteria decreased from the other of  $10^{10}$  cells/ml to the order of  $10^9$  cells/ml after the simultaneous application of insecticide and herbicide (Takamura and Yasuno, 1986).

However changes in bacterial populations were usually followed by a recovery within two or three weeks. Herbicide butachlor had no significant effect on populations of fungi and actinomycetes but possibly increased total populations of bacteria for about two weeks (Chen, 1980). Insecticides sevidol, endrin and gamma-BHC applied at 0.45 to 2.25 kg ai/ha had no adverse effect on the bacterial population and available N, P, and K of the soil observed at harvest (Nair, Ramakrishnan, and Sithanantham, 1974).

A transitory effect of pesticide application at RLFA on microbial populations was also reported for herbicide benthocarb (Sato, 1987). Inhibitory effect of diazinon, carbofuran, and endosulfan at recommended dose were observed on microbial populations at three and nine days after application, but they recovered at twenty days (Roy, Sinha, and Mukhejee, 1975).

One study reported a decrease in rhizospheric BNF measured at sixty and seventy-five days after transplanting in a field where pesticide were sprayed at fifty, sixty, and seventy-five days after transplanting (Nayak and Rao, 1980). On the other hand, two studies of rhizospheric biological  $N_2$  fixation reported a long lasting stimulatory (Mahapatra and Rao, 1981) or inconsistent (Rao, Pasalu, and Rao, 1983) effects of insecticides. This probably reflects more the long-term effects of pesticides on the rice plant than a direct effect on the microflora. The stimulatory effect of gamma-BHC on rhizospheric populations of *Azospirillum* sp. and *Azotobacter* was associated with a reduction of the drop in redox potential of the field soil up to eighty days after transplantation under submerged conditions (Mahapatra and Rao, 1981).

The only field study conducted over several crop cycles (Nishio and Kusano, 1978) showed that nitrification and total bacterial populations in soils having received insecticide for four consecutive years were not significantly different from those in the control. However, counts of bacteria tolerant to organophosphate insecticides were two to four times higher in treated soils.

Considering only results from *in situ* experiments (Table 10.7) provides

Table 10.7. Summary of in situ Data on Microbiological and Algological Effects of Pesticides in Ricefields at Concentrations Corresponding to the Recommended Level for Field Application

| Groups                                  | Number of Data | Percent of Data for Each Effect <sup>a</sup> |                |           |                |              |
|-----------------------------------------|----------------|----------------------------------------------|----------------|-----------|----------------|--------------|
|                                         |                | All Negative                                 | Negative Trend | No Effect | Positive Trend | All Positive |
| Data <i>in situ</i> and <i>in vitro</i> | 606            | 8                                            | 12             | 60        | 11             | 9            |
| Data <i>in situ</i>                     | 351            | 5                                            | 16             | 73        | 5              | 2            |
| Herbicides                              | 50             | 8                                            | 18             | 64        | 10             | 0            |
| Insecticides                            | 297            | 4                                            | 14             | 75        | 4              | 3            |
| Algae                                   | 42             | 7                                            | 10             | 71        | 10             | 2            |
| Actinomycetes                           | 29             | 0                                            | 24             | 76        | 0              | 0            |
| Bacteria                                | 84             | 17                                           | 13             | 57        | 6              | 7            |
| Fungi                                   | 29             | 0                                            | 7              | 86        | 7              | 0            |
| All counts of microorganisms            | 184            | 9                                            | 13             | 68        | 6              | 4            |
| Microbial activities                    | 65             | 0                                            | 45             | 46        | 8              | 2            |
| Soil enzymes                            | 102            | 0                                            | 2              | 98        | 0              | 0            |
| BNF (cyanobacteria not included):       |                |                                              |                |           |                |              |
| BNF all data                            | 93             | 2                                            | 32             | 39        | 15             | 12           |
| BNF populations                         | 35             | 6                                            | 6              | 63        | 3              | 23           |
| BNF activity                            | 58             | 0                                            | 48             | 24        | 22             | 5            |

a. See text for definition of effects.

information measured under realistic conditions but markedly reduces the size of the dataset and the number of conclusions that can be drawn.

Significant effects of pesticides were less often recorded *in situ* than *in vitro* and they were more often negative than positive, whereas the same percentage of positive and negative effects (20 percent) was recorded with the whole dataset.

However, most trends observed with the whole dataset were also observed *in situ*, namely

- More impacts of herbicides than of insecticides;
- A higher sensitivity of bacteria to pesticides than that of fungi, actinomycetes, and algae;
- A higher sensitivity of microbial activities to pesticides than that of population densities. This last trend was especially obvious with data on BNF (Table 10.7); and

- A higher sensitivity of BNF to pesticides (39 percent of no significant effects) than the average sensitivity observed with the whole set of data *in situ* (73 percent of no significant effects).

## 10.6. Conclusions

The impacts of pesticide microflora in wetland soils depends on their persistence, the concentrations attained in the environment, and synergistic/antagonistic effects among pesticides and between pesticides and fertilizers. In ricefields, pesticides can be sprayed, applied in the floodwater, incorporated into the soil, or used for dipping rice seedling at transplanting. The different methods can induce significant differences in pesticide behavior. However, because of the presence of floodwater and puddled soil, a faster dilution can be expected as compared with uplands, where pesticide remains at the soil surface until cultivation or watering incorporates them into the soil. Pesticide degradation in tropical ricefields is favored by (1) temperatures and pH, which usually stabilize in a range favoring high microbial activity, and (2) reducing conditions caused by submersion and further accelerated by organic matter incorporation. Therefore, pesticide degradation is often faster in flooded than in nonflooded soils and other aerobic systems. As a result of a shorter persistence and faster dilution, pesticides should have less impact on soil microflora in wetland ricefields than in upland soils.

In his review on the effects of pesticides on nontarget microorganisms, Anderson (1978) used the notion of "ratio of effects" to analyze 1,016 records on microbiological effects of pesticides in soils. Using sets of experimental data corresponding to various combinations between a group of pesticides and a population or activity, all stimulatory effects, and instances where there was no effect, were counted as positive. All inhibitions were counted as negative. The ratio of positive to negative counts was called the "ratio of effects." The average of twenty-seven ratios calculated by Anderson (1978) for herbicides, fungicides, and insecticides in experiments or observations dealing almost exclusively with upland soil is 1.39, which corresponds to 42 percent of negative effects. The 606 data on wetland soils recorded in our database indicate only 20 percent of negative effects.

About half of 547 papers dealing with the impacts of pesticides on ricefield microflora present quantitative data. However, less than 8 percent of the quantitative studies were conducted *in situ* and a high percentage of the laboratory experiments was conducted at concentrations higher than the RLFA. We selected for analysis only data from experiments conducted at pesticide levels corresponding to the RLFA, but data were also biased in terms of organisms and

pesticides tested. Therefore, their analysis allowed only the identification of general trends.

An absence of effect of pesticides on algae was reported in 39 percent of the total number of records but only in 62 percent of the records obtained *in situ* or in the presence of soil. This confirms that pesticide effects are more marked *in vitro* than *in situ*.

Among pesticides not aiming at algal control, herbicides were most detrimental to algae, causing partial or total inhibition in 67 percent of the *in vitro* tests and in 42 percent of the tests performed *in situ* or in the presence of soil. Recorded effects of pesticides on ricefield algae are: (1) a selective toxicity of all types of pesticides, which affects the composition of the algal population and often favor cyanobacteria, and (2) a short-term growth promoting effect of insecticides on microalgae due to a temporary decrease of invertebrate populations that graze on algae. However, in the long term, insecticide use might cause the proliferation of algal grazers resistant to insecticides such as Ostracods. Grazing pressure may partly explain the dominance in many ricefields of strains of cyanobacteria forming mucilaginous macrocolonies, such as *Nostoc* spp., which are more resistant to grazing than unicellular strains or strains forming individual filaments.

Field studies on algae mostly report an enhancement of algal growth due to insecticide application. Several of these studies were in fact dealing with the promotion of photodependant BNF by controlling grazers with chemical pesticides or pesticides of plant origin.

No bibliographic data are available on long-term effects of pesticides on algae, but studies mostly on cyanobacteria indicate that microalgae can adapt themselves or develop mutants resistant to pesticides.

In 606 tests of the effect of pesticides applied at the recommended dose on a microbial population or activity in wetland soils or in rice rhizosphere, an inhibitory effect was recorded in about 20 percent of the cases, no effect was recorded in about 60 percent of the cases, and a promoting effect was recorded in 20 percent of the cases. Data were biased by the high percentage (73 percent) of records on insecticides. Effects were more frequently observed in laboratory experiments (54 percent of the cases) than *in situ* (27 percent), confirming that small-scale and *in vitro* experiments overestimate pesticide effects. In addition, significant effects were more often negative than positive *in situ*, whereas the same percentage of positive and negative effects (20 percent) was calculated from the whole dataset.

Pesticide effects were more marked in the bulk of soil than in the rhizosphere, which is a more active and probably more resilient microenvironment than the nonrhizospheric soil. Pesticide volatilization through the rice plant may also explain this difference.



Herbicides had more often significant effects (70 percent) than insecticides (32 percent). Microbial activities were more sensitive to pesticides than population densities. This trend was especially obvious with data on BNF. This observation might indicate a short-term effect of pesticides, sufficient to affect metabolic activities but not the viability of the microorganisms.

Within microbial populations, fungi and actinomycetes were less sensitive to pesticides than bacteria.

Data on N cycle show that nitrification was either not affected or negatively affected (34 percent of the cases), which is rather beneficial as it reduces losses from N fertilizer. Denitrification was little affected (13 percent of the cases). With 25 percent of negative effects and 45 percent of positive effects,  $N_2$ -fixing microflora and biological  $N_2$ -fixation were more affected by pesticides than other populations and activities of the N cycle (no effect: 71 percent) but seemed quite versatile in their response to pesticides. A higher number of positive effects was observed indiscriminately with fungicides, herbicides, and insecticides.  $N_2$ -fixing populations were much less affected (no effect: 52 percent) than their activity (no effect: 18 percent).

Data on other aspects of N cycle were not numerous enough to allow conclusions.

Field and laboratory studies with soil usually showed that pesticides applied on soil at recommended levels rarely had a detrimental effect on microbial populations or their activities. When significant changes were observed during tests lasting for several weeks, a recovery of populations or activities was usually observed after one to three weeks.

The analysis of the literature seems to partly confirm the common belief that pesticides applied at recommended levels and intervals are seldom deleterious to the beneficial microorganisms and their activities. Wainright (1978) already concluded that pesticides, with the exception of fumigants and some broad spectrum fungicides, have little deleterious influence on soil processes when applied at field rates. Invertebrate populations seems to be more sensitive to pesticides than microflora (Chapter 9).

However, available information raise several concerns. These are reports of significant effects of pesticides on nontarget microorganisms of importance to soil fertility. Pesticides might have only temporary effects but, when applied repeatedly, could lead to the disappearance or depression of components of the microbial community, thus leading to a new equilibrium and changes in the pattern of their microbial decomposition that might be detrimental.

Several references confirm that ricefield algae, as many microalgae in freshwater environments can significantly contribute to the bioconcentration of pesticides (Table 10.1). This aspect is important when considering the ricefield ecosystem as a possible environment for aquaculture (rice-fish, rice-shrimp).

The major concern is that the current stage of the knowledge on impacts of pesticides in wetland soils is too fragmentary to draw conclusions other than general trends. It is important to emphasize that impacts of pesticides on the soil-floodwater ecosystem can be significant without being detrimental. For example, a shift in algal community structure may not affect soil fertility, providing that aquatic primary production is unchanged. Therefore, one should be cautious when qualifying the nature of impacts that should be considered in the contest of the ecosystem equilibrium and not in isolation. It would be as unwise to under or overestimate the significance of pesticide impacts in wetland soil. Underestimation could cause available ecological damage. Overestimation could restrict the judicious use of pesticide when appropriate.

Studies of the microbial degradation of pesticides and their influence of microflora and microbial activities in flooded rice soils, hitherto mostly restricted to short-term laboratory experiments, must be performed under more realistic field conditions and cultural practices, on a long-term basis.

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# 11 AN EXPERIMENTAL ASSESSMENT OF PESTICIDE IMPACTS ON SOIL AND WATER FAUNA AND MICROFLORA IN WETLAND RICEFIELDS OF THE PHILIPPINES

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## 11.1. Introduction

Research on N nutrition of rice has shown that, whatever the quantity of N-fertilizer applied in a ricefield, most N absorbed by the plant originates from soil. However, only a small fraction of total soil N is available to the plant, and most of this available-N originates from the microbial biomass in soil (Watanabe, De Datta, and Roger, 1988).

Figure 11.1 presents a conceptual scheme of the role of soil microbial biomass in wetland soil fertility and the pathways involved in its replenishment. It emphasizes that rice nutrition depends on the turnover of a small biomass of micro-organisms, which represents only a few percent of total soil N. The replenishment of the microbial biomass requires nutrients, which are provided by (1) crop residues incorporated at the beginning of the crop, (2) rhizosphere exudates, and (3) the photosynthetic aquatic biomass (algae and aquatic plants). Nutrients accumulating in the photosynthetic aquatic biomass (including biologically fixed

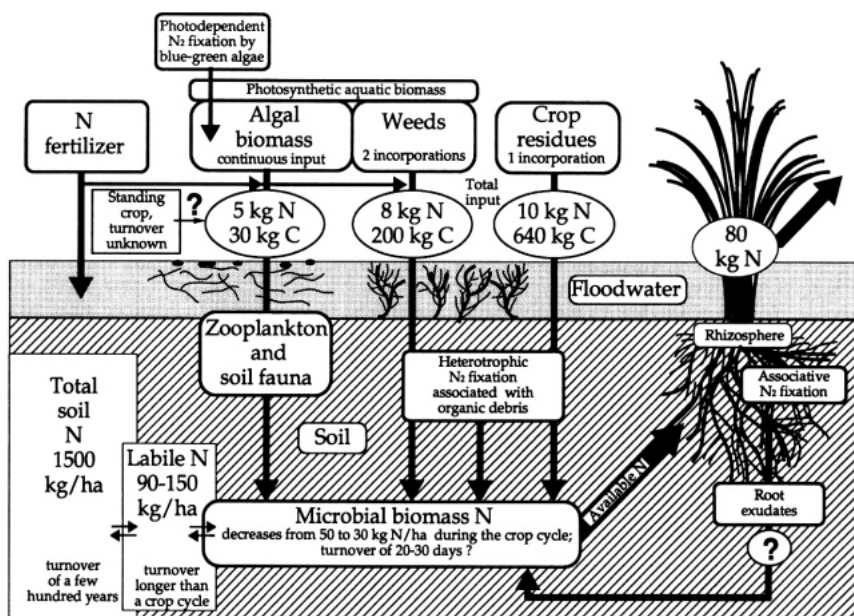


Figure 11.1. Conceptual Scheme of the Role of Soil Microbial Biomass in Wetland Soil Fertility and the Pathways Involved in Its Replenishment

N<sub>2</sub>) are continuously recycled and reincorporated in the deeper soil layer by the zooplankton and the soil fauna, which are therefore key components of the ricefield fertility (Roger, Grant, Reddy, and Watanabe, 1987; Roger and Kurihara, 1991). Preliminary studies, under a restricted number of cultural conditions in the International Rice Research Institute (IRRI) farm, have quantified some of the inputs that allow the replenishment of the microbial biomass (Roger, Jimenez, Ardales, and Watanabe, 1989). However, a comprehensive understanding of the mechanisms involved in this aspect of N-cycling has to be developed. An important aspect is to understand and predict how crop intensification may affect the replenishment of soil microbial biomass. In particular, the overuse of agrochemicals might affect (1) the productivity of the photosynthetic aquatic biomass, (2) the populations of soil and water invertebrates responsible for nutrient recycling, and in turn (3) the microbial biomass and general soil fertility.

This paper summarizes data on pesticide impacts originating from controlled experiments and farmer's fields surveys conducted in the Philippines to assess the effects of agrochemicals on microflora and invertebrates in wetland rice environments. The first set of experiments studied the combined effects of pesticides

and fertilizer in an experimental design of 64 plots in the IRRI farm. The second set of experiments studied the combined effects of pesticide application and fish introduction in an experimental design of twelve plots established at the Central Luzon State University (CLSU) of the Philippines. Field surveys were conducted in thirty-two farms of the Laguna region, where significant levels of agrochemical (average: 1.5 kg active ingredient (ai) of pesticides and 95 kg N,P,K fertilizer/ha/crop) are used and in thirty farms of the Lucban region, where fertilizer use was known to be minimal and pesticide applications absent.

## **11.2. Material and Methods**

### ***11.2.1. Selected Indicators of Pesticide Impacts in Ricefields***

With regard to the methodological problems resulting from soil heterogeneity and the large number of replicated samples needed to obtain significant data in soil biology, the number of variables to be quantified to assess pesticide impacts had to be limited. We selected (1) soil microbial biomass in the upper and lower soil layer, (2) dissolved oxygen concentration in floodwater and N<sub>2</sub>-fixing cyanobacteria populations, (3) aquatic oligochaete populations, and (4) in one of the experiments, major aquatic invertebrates, and molluscs.

The choice of an estimation of total soil microbial biomass to characterize possible effects on microflora was primarily due to our interest in using a method that is faster and less tedious than the classical microbiological methods of direct counts, or indirect counts by plating or inoculating dilutions of soil in selective media. Methods for estimating microbial biomass have been developed for upland soils (Jenkinson and Ladd, 1981), but their application in wetland soils encounters limitations. We used a method derived from the fumigation-incubation technique of Inubushi and Wada (1988), which is only semiquantitative but is faster and less tedious than direct or indirect counts. In addition, the measurement in the nonfumigated control also provided estimates of soil available-N and soil bulk density.

Pesticide effects on the photosynthetic aquatic biomass were assessed from measurements of dissolved oxygen concentration in floodwater at the time of maximum photosynthetic activity, because this value is correlated with the daily primary production in floodwater (Roger, Jimenez, and Santiago-Ardales, 1991). N<sub>2</sub>-fixing cyanobacteria were chosen as the representative component of the photosynthetic aquatic biomass to be enumerated because of (1) their recognized role in maintaining the N-fertility of traditional ricefields and (2) the existence of a large dataset on cyanobacteria in ricefields, which allowed comparisons (Roger, Santiago-Ardales, Reddy, and Watanabe, 1987b).



The choice of aquatic oligochaete to characterize possible effects on soil and water microfauna resulted from the observation that they are a major component of soil fauna in submerged soils and might be an index of soil biological activity. Roger and Kurihara (1991) reported that aquatic oligochaetes were shown to affect weed growth; soil physical, chemical, and microbiological properties; and the nutritional status of floodwater and its flora and fauna. Their major effect is to stimulate organic matter decomposition and to allow the transfer of organic matter,  $\text{NH}_4^+$ ,  $\text{Fe}^{+2}$ ,  $\text{PO}_4^{-2}$ , and soil bacteria to the water. This increases the activity and the biomass of bacteria, and aquatic biota, and results in a feedback effect on the aquatic oligochaete population.

### 11.2.2. *Experimental Designs*

**11.2.2.1. Biological Impacts of Agrochemicals Under Controlled Conditions.** An experimental design of 65 plots (16 sq m each, 5 replicates) was used to study the combined effects of N-fertilizer, the insecticide carbofuran (see Table 11.1 for information on the nature of ai in commercial formulations and their nomenclature), and the herbicide butachlor, on floodwater and soil biology. We used one unplanted unfertilized control and twelve selected combinations of

- Five N treatments: no N, 55 and 110 kg N/ha broadcast split, 55 kg N/ha deep-placed, and *Azolla* incorporated before transplanting; and
- Four levels of pesticides: one application of carbofuran at 0.1 kg ai/ha, two applications of 0.3 kg each, three applications of 0.5 kg each, and five applications of 0.5 kg each. The three treatments with two and five applications of carbofuran also received one application of 0.375 kg ai/ha of Butachlor.

Factor levels were selected to represent a range of situations either prevailing or likely to occur in farmer's fields of the tropical area. Levels of broadcast N-fertilizer were representative of average (55 kg N/ha) and high (110 kg N/ha) level of application by rice farmers. The deep-placement of 55 kg N as urea supergranules is recommended by agricultural research centers to save 30 to 50 percent N-fertilizer. *Azolla* is a green manure that has been traditionally used in China and Vietnam. Level and frequencies of pesticide application were established from a survey in thirty-two farms of the Laguna area where farmers applied between 0.5 and 2.5 kg ai/ha crop cycle (Roger et al., 1990).

To optimize the utilization of available manpower and land facilities, we retained the twelve treatments most likely to be found in farmer fields and one unplanted control among the forty possible combinations of the five N levels,

Table 11.1. Pesticides

| Nature of Active Ingredient in Commercial Formulations |                                                                                                                                                                                                                    |                            |
|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| Insecticides                                           | Herbicides                                                                                                                                                                                                         | Molluscicides              |
| Azocord: Monocrotophos + Cypermethrin                  | 2,4-D: Phenoxy                                                                                                                                                                                                     | Aquatin: Fentin chloride   |
| Azodrin: Monocrotophos                                 | Machete: Butachlor                                                                                                                                                                                                 | Brestan: Fentin acetate    |
| Brodan: Chlorpyrifos + BMPC                            | Solnet: Pretilachlor                                                                                                                                                                                               | Telustan: Fentin hydroxyde |
| Decis: Deltamethrin                                    |                                                                                                                                                                                                                    |                            |
| Diagram: Diazinon                                      |                                                                                                                                                                                                                    |                            |
| Endox: Endosulfan                                      |                                                                                                                                                                                                                    |                            |
| Folidol: Methyl parathion                              |                                                                                                                                                                                                                    |                            |
| Furadan: Carbofuran                                    |                                                                                                                                                                                                                    |                            |
| Hytex: Isoprocarb                                      |                                                                                                                                                                                                                    |                            |
| Lorsban: Chlorpyrifos                                  |                                                                                                                                                                                                                    |                            |
| Thiocarb: Thiobencarb                                  |                                                                                                                                                                                                                    |                            |
| Thiodan: Endosulfan                                    |                                                                                                                                                                                                                    |                            |
| Trebon: Ethofenprox                                    |                                                                                                                                                                                                                    |                            |
| Sevin: Carbaryl                                        |                                                                                                                                                                                                                    |                            |
| Super Gran: Carbofuran                                 |                                                                                                                                                                                                                    |                            |
| Vindex: BPMC + Phentoate                               |                                                                                                                                                                                                                    |                            |
| Nomenclature of Active Ingredients                     |                                                                                                                                                                                                                    |                            |
| 2-4D                                                   | (2,4-dichlorophenoxy) acetic acid                                                                                                                                                                                  |                            |
| BMPC                                                   | 2-sec-butylphenyl methylcarbamate                                                                                                                                                                                  |                            |
| Butachlor                                              | N-butoxymethyl-2-chloro-2',6'-diethylacetanilide                                                                                                                                                                   |                            |
| Carbaryl                                               | 1-naphthyl methylcarbamate. Carbofuran: 2.3-dihydro 2,2-dimethyl-7-benzofuranyl methyl carbamate                                                                                                                   |                            |
| Chlorpyrifos                                           | O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate                                                                                                                                                           |                            |
| Cypermethrin                                           | (RS)-alpha-cyano-3-phenoxybenzyl (1RS,3RS)-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate); (RS)-alpha-cyano-3-phenoxybenzyl (1RS)-cis-trans-3-(2,2-dichlorovinyl)-1, 1-dimethylcyclopropanecarboxylate |                            |
| Deltamethrin                                           | (S)-alpha-cyano-3-phenoxybenzyl (1R,3R)-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropanecarboxylate; (S)-alpha-cyano-3-phenoxybenzyl (1R)cis-3-(2,2-dibromovinyl)-2,2-dimethyl cyclopropanecarboxylate                |                            |
| Diazinon                                               | O,O-diethyl O-2-isopropyl-6-methylpyrimidin-4-yl phosphorothioate                                                                                                                                                  |                            |
| Endosulfan                                             | C,C'-(1,4,5,6,7,7-hexachloro-8,9,10-trinorborn-2,3-ylene) (dimethyl sulphite) 6, 7, 8, 9, 10, 10 -hexachloro -1, 5, 5a, 6, 9, 9a-hexahydro-6, 9-methano-2, 4, 3-benzodioxathiepin 3-oxide                          |                            |
| Fentin                                                 | triphenyltin                                                                                                                                                                                                       |                            |
| Isoprocarb                                             | o-cumenyl methylcarbamate; 2-isopropylphenyl methylcarbamate                                                                                                                                                       |                            |
| Monocrotophos                                          | dimethyl (E)-1-methyl-2-(methylcarbamoyl)vinyl phosphate; 3-(dimethoxy phosphinyloxy)-N-methylisocrotonamide                                                                                                       |                            |
| Parathion                                              | O,O-diethyl O-(4-nitrophenyl) phosphorothioate                                                                                                                                                                     |                            |
| Pretilachlor                                           | 2-chloro-2',6'-diethyl-N-(2-propoxyethyl)acetanilide                                                                                                                                                               |                            |
| Thiobencarb                                            | S-4-chlorobenzyl-diethyl(thiocarbamate)                                                                                                                                                                            |                            |

four pesticide levels, and two rice levels (planted—unplanted). In particular, treatments combining a high level of pesticides with a low level of fertilizers or organic manuring were not retained, as they are very unlikely to be used by farmers.

Measurements performed at regular intervals during the crop cycle included dissolved oxygen in floodwater,  $N_2$ -fixing cyanobacteria, aquatic oligochaetes, and major invertebrates in floodwater: ostracods, copepods, cladocerans, chironomid and mosquito larvae, and aquatic molluscs.

**11.2.2.2. Rice-Fish Culture Experiments.** We studied during two rice-growing seasons some of the biological effects of fish stocking and pesticide use in twelve experimental plots corresponding to four replicates and two treatments (with and without fish x with and without pesticide). The plots were part of two larger experimental designs established at the Central Luzon State University (CLSU, Philippines) for a CLSU, International Center for Living Aquatic Resources Management (ICLARM), IRRI and Institut Francais de Recherche Scientifique Pour le Developpement en Cooperation (ORSTOM) collaborative study of the effects of various managements for rice-fish culture.

Fertilizer was applied in all plots at five (2/3) and thirty days after transplanting (DAT) (1/3) as urea and ammonium phosphate at 106 kg N/ha and 20 kg P/ha. Pesticide-treated plots received 16.7 kg/ha Furadan 3G (granular insecticide with 3 percent ai carbofuran) at 1 DAT, 5 kg/ha Machete 5G (granular herbicide with 5 percent ai Butachlor) at 3 DAT, and Telustan (molluscicide with 60 percent ai triphenyltin hydroxide) applied as a solution (6 tablespoons per liter per 1,200 sq m)<sup>1</sup> at 1 DAT. Tilapia fingerlings (average initial weight about 7 g) were stocked at 11 DAT at 12,000/ha.

Measurements performed at four regular intervals during the crop cycle included dissolved oxygen in floodwater,  $N_2$ -fixing cyanobacteria and aquatic oligochaete populations, and microbial biomass, bulk density, available-N, total N in the surface soil layer (0–2 cm) and the deeper soil layer (2–10 cm) of the soil. Fish yield and rice yield were determined at the end of the crop.

**11.2.2.3. Surveys in Farmers' Fields.** For two consecutive cropping seasons (wet season [WS]; dry season [DS]), available-N, microbial biomass,  $N_2$ -fixing cyanobacteria, and aquatic oligochaetes were quantified in thirty-two farms of the Laguna area and thirty farms of the Lucban, Quezon area (Philippines) where the Social Sciences Division of IRRI had recorded agrochemical use and yields for several years. No pesticide other than rodenticides were used in the farms of the Quezon area. In Laguna area, a wide range of pesticides in terms of formulation (21) and quantity (0.5 to 2.5 kg ai/ha/cropping season) was applied.

Sampling was performed at the beginning of the crop cycle before pesticide application and at the end of the crop cycle, as far as possible from the last pesticide application but before soil dried up. The rationale of this sampling schedule was to study biological variable when short-term effects of pesticide application were not expected to occur and to try to identify the long-term effects of pesticides by correlating biological variables with data on pesticide use in the various farms.

Measurements performed included (1) major physicochemical properties of the soils—that is, pH, C, available P, active iron in the plough layer (0–10cm); and bulk density, available-N, total N in the surface soil layer (0–2cm) and the deeper soil layer (2–10cm), (2) microbial biomass estimated as flush-N in the surface soil layer and the deeper soil layer, and (3) populations of N<sub>2</sub>-fixing cyanobacteria and aquatic oligochaetes.

**11.2.3. Agroecological Data.** Soils were analyzed by the Analytical Services Laboratories of IRRI according to standardized methods, using composite samples of at least five cores, 42 mm in diameter, collected from each site at the beginning of two cropping seasons. In the farmers' fields survey, data on yield and agrochemicals (nature, date of application, quantity applied, and cost) were collected by IRRI's Social Sciences Division.

**11.2.4. Soil Microbial Biomass.** Soil microbial biomass was estimated as the difference in N mineralized after four weeks of incubation in anaerobiosis between a soil sample in which most of the microflora was killed by a treatment with chloroform and an untreated control. This value (flush-N) is an index of the microbial biomass (Jenkinson and Ladd, 1981). The measurement in the nonfumigated control also provides an estimate of soil available-N.

The method we used was modified from that of Inubushi and Wada (1988) for wetland soils. After fumigation, chloroform was removed by evaporation for one hour in a ventilated hood, instead of using a vacuum pump. To obtain an exact estimate of the microbial biomass, flush-N should be multiplied by a correction factor that depends on the nature of the major components of the microflora. This correction factor ( $> 1$ ) has not yet been determined for wetland soils. Therefore, we used noncorrected flush-N values and the method was only semiquantitative. Determinations were done in triplicate on the surface soil layer (0–2cm) and the deeper soil layer (2–10cm) of composite samples comprised of ten cores samples 2.7 cm in diameter. Values of available-N (control) and flush-N (difference between control and chloroform treated soil) were calculated in ppm NH<sub>4</sub>-N on wet and dry soil basis and were extrapolated in kg N/ha on the basis of bulk density measurements.

### 11.2.5. *Photosynthetic Aquatic Biomass*

The effects of pesticides on photosynthetic activity in floodwater were estimated by measuring dissolved  $O_2$  around 1–2 pm. In one experiment, the abundance of floodwater algae was assessed, using a visual index (Roger, Jimenez, and Santiago-Ardales, 1991).

$N_2$ -fixing cyanobacteria were enumerated from composite soil sample comprising ten core subsamples of the top 0.5 centimeter of fresh soil. Suspension-dilutions of soil from 10–2 to 10–6 were plated in triplicate on 1 percent agarized BG-110 medium (Stanier, Kunisawa, Mandel, and Cohen-Bazire, 1971) without mineral-N. Peti dishes were incubated for three weeks at laboratory temperature (22–30°C) under continuous light (800 lux) provided by cold white fluorescent lamps. Counts were performed at two consecutive dilutions under a stereoscopic microscope and were expressed as number of colony forming units (CFU) per sq cm of soil. Detailed information on the methods is available in Roger, Jimenez, and Santiago-Ardales (1991).

### 11.2.6. *Invertebrate Populations*

Zooplankton was studied by enumerating ostracods, copepods, cladocerans, and chironomid and mosquito larvae in composite samples of 5 cores (dia. 71 mm) comprising the floodwater and the surface soil. Samples were washed through stacked 1,000, 750, 500, 350, 250, and 128  $\mu$ m sieves. Material retained on each mesh was backwashed into separate petri dishes and organisms enumerated.

Aquatic oligochaetes were enumerated from composite samples of 10 to 18 soil cores, 27 mm in diameter, collected along a transect in the fields or the experimental plots. The depth of each core sample was determined by the plow layer. Aquatic oligochaetes were extracted by gentle washing with water through 0.25, 1 and 2 mm sieves. Counts were performed on live specimens.

Molluscs were estimated from three surface soil (0–3 cm) samples collected by using 25 x 25 cm metallic quadrants inserted between the rice hills. Soil was washed through 1 and 2 mm sieves.

Population densities were expressed on area bases (number/sq m). Detailed information on the methods is available in Simpson, Roger, Oficial, and Grant (1993b, 1994a, 1994b).

### 11.2.7. *Statistical Methods*

Analysis of variance, correlations, and linear regressions were studied on original data for soil properties, ai of pesticides, available-N and flush-N, and on transformed data for cyanobacteria, aquatic oligochaetes, and zooplankton. Cyanobacteria are known to exhibit log-normal distributions and the counts

were transformed by  $y = \log_{10} (x + 1)$ . Aquatic oligochaete and zooplankton populations exhibited aggregative distributions, which were transformed by  $y = x^{1-b/2}$  where  $b$  is the slope of the regression between logarithms of mean and variances of measurements among replicated plots (Roger, Jimenez, and Santiago-Ardales, 1991). Differences among individual treatments were identified using Least Significant Difference (LSD) multiple range tests at the 95 percent level.

### 11.3. Results

#### 11.3.1. *Biological Impacts of Agrochemicals Under Controlled Conditions*

Results presented in this section are summarized from a series of papers (Simpson, Roger, Oficial, and Grant, 1993b, 1993c, 1994a, 1994b, 1994c), that present results of studies of the combined effects of pesticides and N-fertilizer in a design of sixty-four plots in the IRRI farm.

**11.3.1.1. Impacts on Primary Production.** In plots where N-fertilizer was broadcast, primary production in floodwater exhibited a marked increase (about 10 ppm) for several days after N application due to the proliferation of unicellular eukaryotic algae. In these plots, pesticide application had no significant effect. Incidental significant differences due to pesticide application were observed at the higher pesticide level at four occasions (15, 42–49, and 55 DAT) in the zero N treatment and at three occasions in the deep-placed N treatment (15, 42, and 49 DAT) whereas measurements were performed weekly during the crop cycle (Table 11.2).

**11.3.1.2. Impacts on N<sub>2</sub>-Fixing Cyanobacteria.** Cyanobacteria proliferated in zero N control and fallow plots. A very clear negative correlation between their growth and the quantity of N-fertilizer broadcast was observed. Deep-placement markedly decreased the inhibitory effect of N-fertilizer on cyanobacteria growth (Table 11.2).

On the other hand, pesticide effects were not striking. There was no consistent evidence of significant relationships between cyanobacteria blooms and pesticide regimes across fertilizer treatments or in the four 110 kg N/ha treatments. Some stimulating effect of pesticide application was observed on cyanobacteria abundance when N-fertilizer was not applied or deep-placed. In the absence of N, cyanobacteria blooms developed more rapidly in the 0.3 kg ai/ha  $\times$  2 than in the lower input treatment, but abundance maxima were similar. When N was deep-placed, population development was faster and maximum cover was increased in the higher pesticide treatment. Despite the consistency of these differences, they were mostly not statistically significant.

Table 11.2.    Selected Biological Effects of Rice, Urea, and Pesticides in Experimental Ricefields<sup>a</sup>

| Organisms                            | N-fertilizer      |                |                  | Pesticides               |                    |
|--------------------------------------|-------------------|----------------|------------------|--------------------------|--------------------|
|                                      | Rice <sup>b</sup> | Deep Placement | Increasing Level | All N Treatments at 110N |                    |
|                                      |                   |                |                  | 2 Pesticide Levels       | 4 Pesticide Levels |
| Ostracods                            | -                 | - - -          | + + +            | - (3/11)                 | - (5/45)           |
| Copepods                             | 0                 | 0              | 0                | - (1/11)                 | - (4/45)           |
| Cladocerans                          | -                 | +              | 0                | - (3/11)                 | - (5/45)           |
| Chironomid larvae                    | -                 | - - -          | + + +            | 0                        | 0                  |
| Mosquito larvae                      | +                 | - - -          | + + +            | 0                        | 0                  |
| Aquatic oligochaetes 1990            | nd                | nd             | + +              | - - - <sup>c</sup>       | - - - (11/12)      |
| Aquatic oligochaetes 1991            | nd                | nd             | + +              | + +                      | + +                |
| Snails                               | nd                | nd             | 0?               | nd                       | 0?                 |
| N <sub>2</sub> -fixing cyanobacteria | - - -             | + + +          | - - -            | + + +                    | +                  |
| Dissolved O <sub>2</sub> (0–20 d)    | - - -             | - - -          | + + +            | + (6/32)                 | 0                  |

Source: Summarized from Simpson, Roger, Oficial, and Grant (1993a, 1994a, 1994b, 1994c).  
a. 0 = no effect; + + + or - = clear positive or negative effect; + or - = not very marked, possibly incidental, positive or negative effect (values in parenthesis are the number of significant differences over the total number of records); nd = no data.  
b. Comparison between planted and fallow plots with no N-fertilizer applied.  
c. Effect observed during DS 1990 but not in 1991 where some positive effect was observed.

**11.3.1.3. Impacts on Zooplankton.** The dynamics of invertebrate populations followed a similar pattern in most plots with a peak of chironomid and mosquito larvae at 12 DAT and a peak of ostracods, the most abundant organisms, at 40 DAT. Copepods established early in the crop cycle and increased in number during the second half of the crop cycle. Cladocerans started to multiply only during the last third of the crop cycle. Populations of ostracods, and chironomid and mosquito larvae were much more abundant in the plots receiving the largest quantity of agrochemicals than in fallow plots.

There was a marked positive effect of N-fertilizer broadcasting on populations of algivorous aquatic arthropods (ostracods, and chironomid and mosquito larvae) which developed in response to blooms of readily palatable algae. Populations of dipteran larvae were suppressed by N-fertilizer deep-placement. N-fertilizer had much less effects on populations of copepods and cladocerans (Figure 11.2). When considered at the crop cycle level, aquatic invertebrate populations were not significantly affected by applications of butachlor and carbofuran, especially when N-fertilizer was broadcast in the floodwater (Figure 11.2). Few significant effects were found for ostracods, copepods, and cladocerans by statistical analy-

sis of daily measurements, but they represented a very low percentage of the total number of measurements (Table 11.2). In particular, a few incidental significant differences in copepod densities were observed among pesticide treatment levels. All indicated an inhibitory effect of the highest level of pesticide. Populations of cladocerans, which developed late in the crop season, were significantly denser in the lowest than the highest pesticide treatment from 52 to 85 DAT. The length of time before populations started to expand increased with the quantity of pesticide applied and the time of the last application.

**11.3.1.4. Impacts on Aquatic Oligochaetes.** Populations of aquatic oligochaetes were dominated by tubificidae. Total densities ranged from 0 to 40,000/sq m. Their dynamics were associated with the crop cycle, peak densities being achieved thirty to fifty days after transplanting. Oligochaete numbers increased in response to additions of urea.

An inhibitory effect of carbofuran on oligochaetes was observed during the first season (1990 DS) of pesticide treatments, but not during the following year (1991 DS).

Adverse effects of carbofuran in the 1990 DS (Table 11.2) were expressed as an inhibition from further development relative to treatments that did not receive pesticide and not as density reductions. It was suggested that carbofuran concentrations were insufficient to cause adult mortality but sufficient to affect immature worms, which are more susceptible, thus reducing recruitment to the adult population (Simpson, Roger, Oficial, and Grant, 1993c).

At the start of the 1991 DS, oligochaetes were more numerous in the low-pesticide than the no-pesticide treatments. After pesticides were applied 50 DAT oligochaete population densities remained significantly higher in the presence of pesticides. At 81 DAT after all pesticides and fertilizers had been applied, the interaction between pesticide and N-fertilizer became significant. Oligochaete populations were significantly denser at the high pesticide level only in the absence of mineral-N application. The apparent stimulatory effects of carbofuran in the 1991 DS could be explained by the combined effects of antecedent conditions, the oligochaete life-cycle, and adaptation. Populations in the pesticide-treated plots were depressed the previous year. If resources were underused, populations could have developed to exploit them during the wet fallow period. Oligochaete density reductions caused by carbofuran in the 1990 DS were probably not a consequence of adult mortality. Therefore, established adult populations may not decline after pesticide applications but could be prevented from further increase (Table 11.3).

**11.3.1.5. Impacts on Aquatic Molluscs.** The most abundant snail species recorded were *Melanoides tuberculata* and *Melanoides granifera*. Snails were more abundant in fallow than in planted plots where they declined as the crop



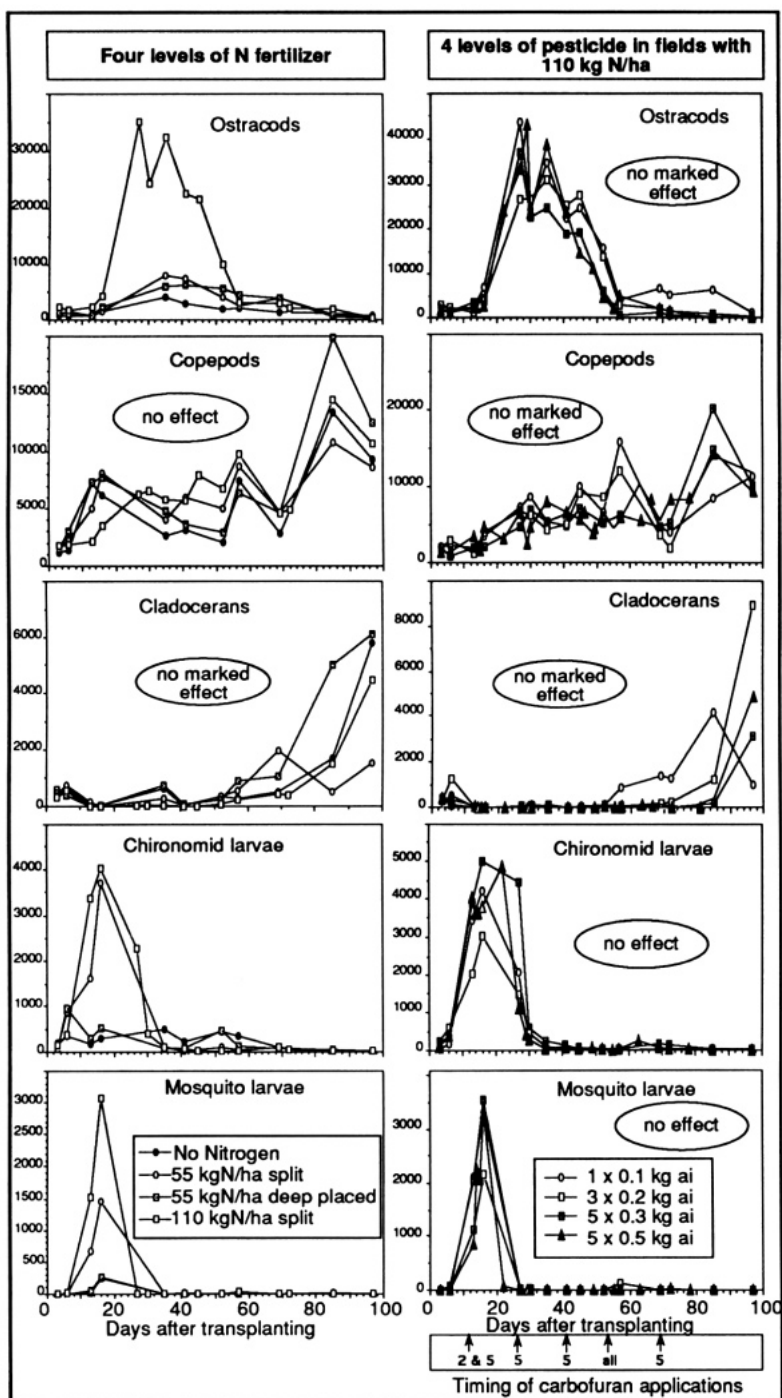


Table 11.3. Aquatic Oligochaete Populations (hundred/sq m) During the 1991 DS and One-way ANOVA Analysis on Log-Transformed Data

|                      | <i>Days after Transplanting</i> |                  |                  |                 |                   |                  |
|----------------------|---------------------------------|------------------|------------------|-----------------|-------------------|------------------|
|                      | <i>-3</i>                       | <i>18</i>        | <i>39</i>        | <i>60</i>       | <i>81</i>         | <i>Mean</i>      |
| ANOVA (P values)     | 0.23                            | 0.01             | 0.01             | 0.01            | 0.01              | 0.01             |
| No N-fertilizer:     |                                 |                  |                  |                 |                   |                  |
| No pesticide         | 64                              | 36 <sup>a</sup>  | 64 <sup>ab</sup> | 28 <sup>a</sup> | 30 <sup>ab</sup>  | 45 <sup>a</sup>  |
| Low pesticide level  | 146                             | 91 <sup>c</sup>  | 63 <sup>ab</sup> | 58 <sup>b</sup> | 54 <sup>bc</sup>  | 82 <sup>b</sup>  |
| High pesticide level | 91                              | 75 <sup>bc</sup> | 7g <sup>b</sup>  | 84 <sup>c</sup> | 116 <sup>d</sup>  | 89 <sup>b</sup>  |
| 110 kg N/ha:         |                                 |                  |                  |                 |                   |                  |
| No pesticide         | 66                              | 69 <sup>bc</sup> | 97 <sup>b</sup>  | 58 <sup>b</sup> | 71 <sup>bcd</sup> | 72 <sup>b</sup>  |
| Low pesticide level  | 95                              | 68 <sup>bc</sup> | 89 <sup>b</sup>  | 75 <sup>b</sup> | 79 <sup>cd</sup>  | 81 <sup>b</sup>  |
| High pesticide level | 110                             | 123 <sup>c</sup> | 101 <sup>b</sup> | 72 <sup>b</sup> | 112 <sup>d</sup>  | 104 <sup>b</sup> |

Note: Numbers followed by the same letter are not significantly different at the five percent level.  
Source: After Simpson, Roger, Oficial, and Grant (1993b).

season progressed. Populations were significantly reduced by the broadcast N-fertilizer at 110 kg N/ha. Changes in snail numbers were more dramatic than changes in biomass, partly because smaller snails were more affected by treatments, and they contribute little to the biomass. Limited evidence suggested that snails were favored by carbofuran and/or butachlor applications (Table 11.4).

**11.3.1.6. Conclusion.** These experiments, conducted at rates of agrochemicals currently used in farmer fields, showed that, as a general trend, N-fertilizer application and the presence of rice plant had more effects on studied populations than pesticides.

Figure 11.2. Effect of N and Pesticides on the Dynamics of Major Components of the Zooplankton in Experimental Plots, IRRI, 1990 DS

Notes: Figures on the left side present average values (five replicated plots) of treatments with:

- no fertilizer,
- 55 kg N/ha broadcast,
- 55kg N/ha deep-placed, and
- and 110 kg N/ha broadcast.

Figures on the right side show the effects of four levels of pesticide in plots receiving 110 kg N/ha.

- 1 × 0.1 = 1 application of 0.1 kg ai/ha carbofuran
- 2 × 0.3 = 2 applications of 0.3 kg ai/ha carbofuran + 1 application of 0.375 kg ai/ha butachlor
- 5 × 0.3 = 5 applications of 0.3 kg ai/ha carbofuran + 1 application of 0.375 kg ai/ha butachlor
- 5 × 0.5 = 5 applications of 0.3 kg ai/ha carbofuran + 1 application of 0.375 kg ai/ha butachlor

Table 11.4. Summary of Snail Population Densities (nb/sq m) for Individual Plots in Each Treatment After Transplanting in 1990 and 1991 DS

| <i>Treatment</i>           | <i>Dry Season 1990</i> |             |             | <i>Dry Season 1991</i> |             |             |
|----------------------------|------------------------|-------------|-------------|------------------------|-------------|-------------|
|                            | <i>Min.</i>            | <i>Mean</i> | <i>Mar.</i> | <i>Min.</i>            | <i>Mean</i> | <i>Mar.</i> |
| Populations (number/sq m): |                        |             |             |                        |             |             |
| 0 kg N/ha                  | 17                     | 370         | 1,533       | 0                      | 275         | 1,042       |
| 110 kg N/ha                | 0                      | 77          | 533         | 0                      | 42          | 117         |
| 110 kg N/ha + pesticides   | 17                     | 167         | 633         | 0                      | 67          | 283         |
| Fallow                     | -                      | -           | -           | 107                    | 550         | 2,042       |
| Biomass (kg/ha):           |                        |             |             |                        |             |             |
| 0 kg N/ha                  | 50                     | 250         | 1,060       | 0                      | 190         | 590         |
| 110 kg N/ha                | 0                      | 90          | 380         | 0                      | 60          | 470         |
| 110 kg N/ha + pesticides   | 0                      | 200         | 580         | 0                      | 80          | 310         |
| Fallow                     | -                      | -           | -           | 90                     | 300         | 1,080       |

Source: Simpson, Roger, Oficial, and Grant (1994c, 1994a, 1994b).

Floodwater biology was markedly affected by N-fertilizer broadcasting and only incidentally by pesticides. N-fertilizer broadcasting markedly stimulated floodwater primary productivity, favoring the growth of unicellular algae, which resulted in the proliferation of algivorous aquatic arthropods. Pesticides had no marked effect on these organisms when considered at the crop cycle level.

Aquatic oligochaetes exhibited a significant negative response to pesticide application in the first DS crop cycle; however, this effect was not reproducible over two successive DS crops.

Pesticide impacts were (1) usually not observed in the presence of broadcast fertilizer, and (2) incidental and limited in plots where N-fertilizer had no or limited effects on floodwater ecology (i.e., N-fertilizer either not applied or deep-placed). However, in farmers' fields, pesticides are usually not used in the absence of fertilizer.

### 11.3.2. Rice-Fish Culture Experiments

In both experiments, measurements were performed at four regular intervals during the crop cycle. The measurement at the beginning of the crop served as reference. As pesticides were applied only at transplanting, their effect was expected to be more obvious during the early part of the crop cycle. Therefore, Table 11.5, which summarizes the results of pesticide effects in the two experiments, presents the analysis of the measurements performed about one month

Table 11.5. Effects of Pesticide Treatment on Selected Biological Indicators and Yields, and Significance (p) of the Differences Observed in Two Rice-Fish Culture Experiments<sup>a</sup>

| Variable                                               | 1st crop (WS) |       |                   | 2nd crop (DS) |       |        |
|--------------------------------------------------------|---------------|-------|-------------------|---------------|-------|--------|
|                                                        | Pesticide     |       | Fish <sup>b</sup> | Pesticide     |       | Fish   |
|                                                        | -             | +     | p                 | -             | +     | Effect |
| Dissolved O <sub>2</sub> (ppm)<br>(average 0–23 DT)    | 7.4           | 13.5  | 0.01              | 13.8          | 14.9  | 0.47   |
| Dissolved O <sub>2</sub> (ppm)<br>(average crop cycle) | 7.0           | 8.7   | 0.02              | 9.6           | 9.5   | 0.88   |
| Bulk density of surface soil                           | 0.75          | 0.70  | 0.60              | 0.65          | 0.65  | 0.86   |
| (g cu m)                                               | 0.703         | 0.743 | 0.34              | 0.724         | 0.718 | 0.80   |
| N content of surface soil                              | 0.126         | 1.130 | 0.83              | 0.131         | 0.135 | 0.80   |
| (%)                                                    | 0.122         | 0.124 | 0.84              | 0.122         | 0.130 | 0.45   |
| N change in surface soil <sup>c</sup>                  | 0.024         | 0.033 | 0.23              | 0.014         | 0.018 | 0.25   |
| (%)                                                    | 0.022         | 0.030 | 0.03              | 0.010         | 0.015 | 0.06   |
| Avail. N in surface soil                               | 5.04          | 5.48  | 0.40              | 5.39          | 3.83  | 0.38   |
| (ppm NH <sub>4</sub> -N dry soil)                      | 4.17          | 4.67  | 0.55              | 3.51          | 3.46  | 0.89   |
| Avail. N in surface soil                               | 7.48          | 7.54  | 0.80              | 6.05          | 5.00  | 0.04   |
| (kg/ha)                                                | 5.84          | 5.81  | 0.80              | 4.81          | 4.88  | 0.84   |
| Flush-N in surface soil                                | 11.40         | 9.70  | 0.46              | 11.40         | 11.60 | 0.93   |
| (ppm NH <sub>4</sub> -N dry soil)                      | 8.04          | 8.36  | 0.71              | 9.00          | 9.36  | 0.64   |
| Flush-N in surface soil                                | 16.40         | 13.00 | 0.10              | 14.73         | 15.11 | 0.32   |
| (kg/ha)                                                | 11.22         | 12.19 | 0.20              | 12.72         | 13.15 | 0.70   |

Table 11.5. (Continued)

| Variable                                  | 1st crop (WS) |      |                   | 2nd crop (DS) |      |        |
|-------------------------------------------|---------------|------|-------------------|---------------|------|--------|
|                                           | Pesticide     |      | Fish <sup>b</sup> | Pesticide     |      | Fish   |
|                                           | -             | +    | p                 | -             | +    | Effect |
| N2-fixing cyanobacteria (CFU/sq m x 10-4) | 9.00          | 6.40 | 0.30              | 3.20          | 4.30 | 0.21   |
| mean                                      | 6.70          | 5.40 | 0.40              | 2.30          | 3.40 | 0.16   |
| Oligochaetes                              | 3,068         | 81   | 0.01              | 4,538         | 1147 | 0.01   |
| mean                                      | 1,130         | 118  | 0.01              | 2,390         | 689  | 0.18   |
| Fish yield <sup>d</sup> (kg/ha)           | 199           | 179  | 0.36              | 233           | 202  | 0.63   |
| Rice yield <sup>d</sup> (t/ha)            | 3.82          | 4.16 | 0.18              | 4.12          | 4.88 | 0.10   |

a. Each value is the average of measurements in four replicated plots performed at three regular intervals after treatments were applied. 2nd refers to the second measurement: mean refers to the average of the second, third, and fourth measurements (see text). Surface soil refers to the 0-2cm layer. Soil N, bulk density, available-N (ppm NH<sub>4</sub>-N and kg/ha), and flush-N (ppm NH<sub>4</sub>-N and kg/ha) were also measured in lower soil (2-10cm) but showed no effect of pesticide treatment.

b. Only significant effects are indicated; + = positive effect, - = negative effect at p < 0.05.

c. Difference in N content between the upper (0-2 cm) and the deeper (2-10 cm) soil layer.

d. The analysis of the data in the larger experimental designs of twenty-four plots and eight rice-fish managements indicated significant positive effects of pesticide application on rice yield and negative effects on fish yield.

after transplanting (second measurement) and the average value of the second, third, and fourth measurements performed after the treatments were applied.

Both experiments showed a quite large variability among replicated plots. Variability in rice yield was due to a marked incidence of golden snails, which damaged or destroyed patches of newly transplanted seedlings. Variability of fish yield was due to the development of a predator fish (*Ophicephalus striatus*) in some plots. Total N, available-N, and flush-N measurements also exhibited a high variability among replicated plots. In upper soil, the coefficients of variation of total soil N estimates ranged from 12.9 to 37 percent and averaged 18.3 percent; the coefficients of variation of flush-N measurements ranged from 15 to 28 percent and averaged 20 percent. The average of the three measurements performed during the crop had a lower variability than individual measurements, but coefficients of variation were still high, ranging from 12.2 to 18.8 percent and averaging 15.8 percent. This situation was not exceptional as observed by App et al. (1984). It may partly explain why little significant differences were observed between plots receiving and not receiving pesticides, and call for caution when interpreting the data.

Pesticide application caused a statistically significant increase of the photosynthetic activity in the floodwater at the beginning of the WS crop cycle (Table 11.5). During the DS, photosynthetic activity in floodwater was still higher in plots where pesticide were applied, but the difference was not statistically significant.

No significant effect of pesticide application was observed on the total-N, available-N, and flush-N content of surface soil. In order to alleviate the effects of the large variability among replicated plots, variance analysis was performed on (1) difference between each of the second, third, and fourth measurement and the first measurement, and (2) differences between measurements in the upper and the lower soil layer. Over sixty-three variance analysis performed on individual (second, third, and fourth) measurements or their average, p values lower than 0.05 were obtained in only eight cases and p values lower than 0.10 in twelve cases. The only significant effect observed in both seasons indicated that, on the average, pesticide application increased the difference in N content between the upper and the lower soil layers. This might reflect the increase in floodwater primary production in plots where pesticide was applied. Significant effects observed in surface soil on available-N, and, possibly, on flush-N were observed only for one season and might have been incidental.

No significant effect of pesticide application was observed in the total-N, available-N, and flush-N measurements and related calculated variables performed on the deeper soil layer.

The most consistent effect of pesticide application was a significant inhibition of aquatic oligochaetes, which was observed in both seasons.

There was no significant effect on populations of  $N_2$ -fixing cyanobacteria, and fish and rice yields when analysis was performed on twelve plots. However, the analysis of the data in the larger experimental designs (twenty-four plots and eight managements for rice-fish culture) indicated a significant positive effect of pesticide application on rice yield and a negative effect on fish yield.

The effects of fish stocking were more often significant than those of pesticide application ( $p < 0.05$  in sixteen cases over sixty-three variance analysis). Fish stocking significantly increased N content and microbial biomass of the surface soil and decreased the bulk density of the surface soil (Table 11.5).

### 11.3.3. *Surveys in Farmers' Fields*

Available-N, microbial biomass,  $N_2$ -fixing cyanobacteria, and aquatic oligochaetes were quantified for two consecutive seasons, at the beginning and at the end of the crop cycle (when short-term effects of pesticide application were not expected to occur), in thirty-two farms of the Laguna area where pesticides were used, and thirty farms of the Lucban, Quezon area where no pesticide other than rodenticides were used. The rationale of this study was to take advantage of extensive data on pesticide utilization collected during a survey conducted by the Social Sciences Division of IRRI, to try to identify long-term effects of pesticides on soil and water biology by (1) comparing farms where pesticides were or were not used and (2) studying correlations between biological variables and pesticide use.

**11.3.3.1. Comparison Between Sites.** Results of analyses showed significant differences in the mean values of all the quantified variables in Laguna and Quezon areas, including N-fertilizer application and soil properties (Table 11.6). Therefore, significant differences in soil physicochemical properties between both areas strongly limited the utilization of Quezon area as a no-pesticide control for measurements performed in Laguna area where pesticide was used.

Flush-N, available-N, and densities of cyanobacteria and aquatic oligochaetes were significantly lower in Quezon area, where no pesticide was used, than that in Laguna area. However, these differences were most probably attributable more to soil properties and environmental conditions than to pesticide use.

Published data on microbial biomass estimate in wetland soils are too scarce to allow comparison with those collected during the survey. Soils in Laguna area are more fertile than in Quezon area, as indicated by available-N and P contents and rice yield. A higher microbial biomass in Laguna soils might be associated with these trophic properties. No conclusion regarding pesticide effects could be drawn.

Table 11.6. Comparison of Agrochemical Use, and Average Soil and Biological Properties in Laguna and Lucban, Quezon Areas

|                                    | Laguna Area |             | Quezon Area |             | P  |
|------------------------------------|-------------|-------------|-------------|-------------|----|
|                                    | Mean        | Range       | Mean        | Range       |    |
| Agrochemical use:                  |             |             |             |             |    |
| Pesticides (kg ai/ha/crop)         | 1.5         | (0.5–2.5)   | 0.0         | (0.0–0.0)   | ** |
| Fertilizer N DS (kg/ha/crop)       | 103         | (33–184)    | 35          | (8–92)      | ** |
| Fertilizer N WS (kg /ha/crop)      | 67          | (0–134)     | 22          | (7–60)      | ** |
| Soil physicochemical properties:   |             |             |             |             |    |
| PH                                 | 6.37        | (5.7–7.5)   | 5.6         | (4.7–6.1)   | ** |
| C (%)                              | 2.23        | (1.48–3.35) | 2.55        | (1.99–3.17) | ** |
| N (%)                              | 0.22        | (0.15–0.31) | 0.28        | (0.19–0.60) | ** |
| C/N                                | 10.0        | (7.5–11.7)  | 9.3         | (5.3–11.2)  | ** |
| Available P (Olsen) ppm            | 31.3        | (2.7–81)    | 8.2         | (2.2–71)    | ** |
| Active Fe                          | 1.13        | (0.34–2.36) | 3.59        | (1.61–4.57) | ** |
| Bulk density, 0–2 cm (g dw/cu cm)  | 0.59        | (0.45–0.75) | 0.43        | (0.28–0.61) | ** |
| Bulk density, 0–10 cm (g dw/cu cm) | 0.67        | (0.50–0.89) | 0.54        | (0.33–0.56) | ** |
| Biological properties:             |             |             |             |             |    |
| Available-N, 0–2 cm (kg/ha)        | 8.0         | (4.4–27.7)  | 5.6         | (3.2–8.3)   | ** |
| Available-N, 0–10 cm (kg/ha)       | 27.2        | (16–89)     | 19.3        | (10–33)     | ** |
| Flush-N, 0–2 cm (kg/ha)            | 18.7        | (9.8–33.7)  | 8.4         | (5.1–14.0)  | ** |
| Flush-N, 0–10 cm (kg/ha)           | 84.7        | (51–134)    | 44.0        | (22–72)     | ** |
| Cyanobacteria (1,000/sq cm)        | 87          | (30–300)    | 17          | (0.7–94)    | ** |
| Aquatic Oligochaetes (1,000/sq m)  | 6.2         | (0.1–18.3)  | 1.2         | (0–16.8)    | ** |

Note: Values are the average of four measurements at the sequencing and the end of the WS and DS.

Cyanobacteria abundance in both sites was within the range most commonly encountered in ricefields ( $10^3$ – $10^5$ /cm<sup>2</sup>). As in most ricefields, populations were dominated by *Nostoc* spp. and genera forming mucilaginous colonies of definite shape (Roger, Santiago-Ardales, Reddy, and Watanabe, 1987b). On the average cyanobacteria were about five times more abundant in Laguna than in Quezon soils. This might be explained by the higher pH and available P contents of the Laguna soils. Positive correlations between (1) cyanobacteria abundance and (2) soil pH and available P have been reported for a broad range of soils (Roger, Santiago-Ardales, Reddy, and Watanabe 1987b). In addition, reports in the literature indicate an enhancement of cyanobacteria growth by insecticide application. None of the observations made allowed to conclude that differences observed between cyanobacteria populations in the two sites were attributable to pesticide, because both insecticides (often reported to favor cyanobacteria), and herbicide



(often reported to be detrimental to cyanobacteria) were used in most farms of Laguna.

Aquatic oligochaete population in both regions were dominated by *Limnodrilus hoffmeisteri* and *Branchiura sowerbyi*. Some species were recorded in one region and not in the other, but similar number of species were recorded in both regions. Species diversity was low, and average Simpson's diversity indices were not significantly different between both regions. The range of population densities was similar in both regions (0 to 45,000/sq m), but in Quezon most populations were below 2,500/sq m and the average was significantly lower than in Laguna. Median densities were 190 and 4,050/sq m, respectively. A lower aquatic oligochaete population in Quezon area might be attributed to the general soil acidity and the usually long lasting dry fallow period in this area. The organic matter and the water contents of the soils in Quezon area were higher than threshold values (1.75 percent carbon and 80 percent water dw.basis) that seems to limit the growth of aquatic oligochaetes (Simpson, Roger, Oficial, and Grant, 1993b). Populations of oligochaetes were denser in soils where pesticides were applied, but none of the observations made allowed researchers to draw conclusions regarding the effects of pesticide use on the relative abundance of aquatic oligochaetes in the two sites.

Because the comparison of biological variables in areas where pesticides were used or not used was refrained by significant differences in soil properties between both areas, another approach was tried by restricting the study to the Laguna area and analyzing correlations between biological variables and pesticides use in the thirty-two farms surveyed in this area.

#### **11.3.3.2. Relations Between Pesticide Use and Biological Characteristics in Laguna Area**

*Pesticide Use in Laguna Area.* All farmers used pesticides at various levels, at least during the DS (Table 11.7). The nature of insecticides was extremely variable: during the survey of biological properties of the soils, fifteen formulations were used during the DS and eight during the WS. As a result, each formulation was used by a few farmers only, Brodan was most frequently applied (in nine farms during the DS and in ten farms during the WS). The rates of utilization of a given insecticide were quite variable, with ratios between maximum and minimum rate ranging from one to 40. This extremely high ratio (considering that there is one recommended level of application) was due to one farmer, who applied a "cocktail" of several insecticides at reduced level. For the two formulations of herbicides applied, the ratio between maximum and minimum rate of application was about 4.5. Molluscicides were used in four farms during the DS and in twelve farms during the WS.

Table 11.7. Commercial Pesticides Used, Number of Users, and Quantity of ai Applied per Crop (kg ai/ha) in Laguna Area During the Biological Soil Survey

| Pesticide      | Dry Season      |                     |      |      | Wet Season      |                     |      |      |
|----------------|-----------------|---------------------|------|------|-----------------|---------------------|------|------|
|                | Number of Users | Rate of Utilization |      |      | Number of Users | Rate of Utilization |      |      |
|                |                 | Maxi                | Mini | Mean |                 | Maxi                | Mini | Mean |
| Insecticides:  |                 |                     |      |      |                 |                     |      |      |
| Azocord        |                 |                     |      |      |                 |                     |      |      |
| + Azodrin      | 11              | 0.67                | 0.01 | 0.25 | 6               | 0.33                | 0.10 | 0.2s |
| Brodan         | 9               | 0.53                | 0.10 | 0.25 | 10              | 0.42                | 0.11 | 0.21 |
| Decis          | 2               | 0.01                | 0.01 | 0.01 | 2               | 0.02                | 0.00 | 0.01 |
| Diagran        | 1               | -                   | -    | 0.67 | 0               | -                   | -    | -    |
| Endox          | 1               | -                   | -    | 0.58 | 0               | -                   | -    | -    |
| Folidol        | 3               | 0.83                | 0.02 | 0.39 | 1               | -                   | -    | 0.21 |
| Furadan        | 4               | 0.37                | 0.01 | 0.20 | 4               | 0.46                | 0.32 | 0.39 |
| Hytox          | 1               | -                   | -    | 0.21 | 3               | 0.29                | 0.11 | 0.20 |
| Lorsban        | 0               | -                   | -    | -    | 4               | 0.64                | 0.21 | 0.45 |
| Thiocarb       | 2               | 0.02                | 0.01 | 0.02 | 0               | -                   | -    | -    |
| Thiodan        | 8               | 0.66                | 0.01 | 0.31 | 6               | 0.22                | 0.10 | 0.15 |
| Trebon         | 3               | 0.20                | 0.07 | 0.12 | 0               | -                   | -    | -    |
| Sevin          | 1               | -                   | -    | 0.95 | 0               | -                   | -    | -    |
| Super gran     | 1               | -                   | -    | 0.70 | 0               | -                   | -    | -    |
| Vindex         | 1               | -                   | -    | 0.01 | 0               | -                   | -    | -    |
| Herbicides:    |                 |                     |      |      |                 |                     |      |      |
| 2,4-D          | 1               | -                   | -    | 0.33 | 9               | 0.40                | 0.07 | 0.16 |
| Machete        | 25              | 0.71                | 0.16 | 0.40 | 22              | 0.65                | 0.14 | 0.34 |
| Solnet         | 1               | -                   | -    | 0.01 | 0               | -                   | -    | -    |
| Molluscicides: |                 |                     |      |      |                 |                     |      |      |
| Aquatin        | 3               | 0.07                | 0.09 | 0.08 | 8               | 0.18                | 0.10 | 0.11 |
| Brestan        | 1               | -                   | -    | 0.29 | 4               | 0.39                | 0.10 | 0.19 |

| Summary of Quantities of ai Used |             |      |           |      |              |      |
|----------------------------------|-------------|------|-----------|------|--------------|------|
|                                  | Insecticide |      | Herbicide |      | Molluscicide |      |
|                                  | DS          | WS   | DS        | WS   | DS           | WS   |
| Maximum                          | 1.76        | 1.06 | 0.71      | 0.74 | 0.29         | OS3  |
| Minimum                          | 0.00        | 0.00 | 0.00      | 0.00 | 0.00         | 0.00 |
| Average                          | 0.47        | 0.27 | 0.37      | 0.29 | 0.02         | 0.05 |
| Standard deviation               | 0.34        | 0.27 | 0.16      | 0.17 | 0.06         | 0.10 |

The quantities of ai of individual pesticides used per cropping season averaged about 0.3 kg/ha/crop and did not exceed 1 kg/ha/crop. The total quantities of ai used during a cropping season in a field ranged from 0.5 to 2.5 kg/ha. Most values were between 1 and 2 kg/ha. More pesticide was used during the DS than during the WS (Table 11.7). During the DS, when a wider range of pesticide was used, the number of different formulations used per field varied from one to eight and averaged three. Five farmers utilized more than three different pesticides.

Because of the variability of the nature of pesticides used in Laguna area, no fully satisfactory quantification of overall pesticide utilization among farms could be established.

The first approach considered the quantity of ai of insecticide, herbicide, molluscicide, and total pesticides applied per hectare during the DS and WS of the soil survey. This method of calculation was biased because the quantities of ai required to be active vary among pesticides; some, such as Decis, require very low levels. Cluster and principal component analysis using ai of pesticides and number of applications as descriptors did not show any grouping that would have permitted to compare sets of farms with low, medium, and high pesticide use.

The second approach, intended to express both the intensity and the history of pesticide use in the farm by considering the cost of pesticides groups (insecticide, herbicide, molluscicide, and their sum) applied per hectare in each field during the two seasons of the soil survey and the five previous cropping seasons. Indeed this method was biased by commercial aspects, but one can expect such an estimate to be less dependent upon the quantity of ai required to be active because what is roughly priced in a commercial formulation is the quantity of ai necessary for an efficient application.

In a first approach, all possible correlations between (1) the measurements performed at individual sampling times, or their combinations, or their means, and (2) the estimates of ai of pesticide groups applied in both seasons of the soil survey (WS, DS, sum), and the number of applications (WS, DS, and sum) were tested. In total, 420 individual correlations were studied corresponding to the cross tabulation of

- Twenty-eight sets of data on biological variables:  
Aquatic oligochaetes and cyanobacteria:  $(4 \text{ estimates} + \text{average}) \times 2 = 10$   
Flush-N:  $(5 \text{ estimates} + \text{average}) \times (\text{upper soil, lower soil, average}) = 18$
- Fifteen sets of data on pesticide application:  
Insecticide: (WS, DS, sum = 3); Herbicide: 3; Molluscicide: 3; Sum pesticides: 3; = 12  
Number of applications (WS, DS, and sum) = 3

In a second approach, data were aggregated or selected in order to study cross-correlations between a limited number of values representative of the average physicochemical status, biological status, and the long-term utilization of pesticide in each field.

Soil physicochemical properties recorded from two independent sampling (WS and DS) were highly correlated ( $r > 0.95$  for pH, C, and available P;  $r > 0.8$  for N). Therefore, average values were used. The two expressions of bulk density were highly positively correlated to each other and both were highly negatively correlated with soil humidity. Carbon and N content were also highly positively correlated to each other. Therefore, only bulk density (g dry weight/cu cm) and total soil N were considered. Bulk density, available-N, and flush-N measurements performed in the 0–2 and 2–10 cm layers were highly positively correlated to each others and highly correlated to their respective sums or average in the 0–10cm layer. Therefore, only their sums or average value in the 0–10 cm layer were considered.

For biological variables, measurements performed at individual sampling times (transplanting and crop maturity in the DS and WS) were highly positively correlated with overall farm means ( $p < 0.01$ ). Therefore, only mean values were used to study correlations with pesticide use.

The correlations between aggregated/elected data and both estimates of pesticide use (ai and cost) are presented in Table 11.8.

*Results and Discussion.* (1) *Soil properties:* Laguna soils showed a range of variation in their physicochemical properties (Table 11.6) that allowed to recognize five groups by cluster and principal component analysis, using pH, C, N, P, and active Fe as descriptors. Groups corresponded to the geographical distribution of the fields (data not shown). Average contents in C (2.23 percent), N (0.22 percent), and available-P (30 ppm) indicated an average fertility higher than that of Asian and Philippine rice soils. For comparison, Kawaguchi and Kyuma (1977) reported average contents of 1.4 percent C, 0.13 percent N, and 21 ppm available P in 410 rice soils of tropical Asia. pH was positively correlated with soil organic matter content (C and N) and negatively with Olsen P (Table 11.8). This is not a general feature of rice soils but a characteristic of the set of soils studied.

Significant correlations were found between (1) total pesticide applied and soil pH ( $r = -0.356$ ,  $p < 0.05$ ), (2) molluscicide and available-P, (3) herbicide with available-P and bulk density, and (4) total pesticide and bulk density (Table 11.8). Indeed, such correlations are either spurious, occurring by accident, or highly indirect. They have to be kept in mind when interpreting correlations between biological variables and pesticide use.

(2) *Microbial biomass:* Flush-N was positively correlated with soil pH and

Table 11.8. Correlations Between Soil Properties, Selected Biological Variables, and Two Estimations of the Intensity of Pesticide Use in Thirty-Two Ricefields of the Laguna Area

|             | <i>pH</i>     | <i>N</i>      | <i>C/N</i>    | <i>Average Active</i> |                 | <i>Bulk Density</i> | <i>N</i>      | <i>FlushN</i> | <i>Cyano</i> | <i>Oligochaete</i> | <i>Insecticide</i> | <i>Herbicide</i> | <i>Molluscide</i> | <i>Pesticide</i> |
|-------------|---------------|---------------|---------------|-----------------------|-----------------|---------------------|---------------|---------------|--------------|--------------------|--------------------|------------------|-------------------|------------------|
|             |               |               |               | <i>P</i>              | <i>Fe(iron)</i> |                     |               |               |              |                    |                    |                  |                   |                  |
| <i>pH</i>   | +1.000        |               |               |                       |                 |                     |               |               |              |                    |                    |                  |                   |                  |
| <i>N</i>    | <u>+0.445</u> | 1.000         |               |                       |                 |                     |               |               |              |                    |                    |                  |                   |                  |
| <i>C/N</i>  | -             | -             | 1.000         |                       |                 |                     |               |               |              |                    |                    |                  |                   |                  |
| Average     | -0.294        | <u>-0.506</u> | -0.297        | 1.000                 |                 |                     |               |               |              |                    |                    |                  |                   |                  |
| Act.Fe      | <b>-0.646</b> | <u>-0.480</u> | -             | +0.293                | 1.000           |                     |               |               |              |                    |                    |                  |                   |                  |
| BD          | -0.304        | <u>-0.638</u> | <u>-0.430</u> | <u>+0.576</u>         | +0.390          | 1.000               |               |               |              |                    |                    |                  |                   |                  |
| Average N   | -             | -             | <u>-0.690</u> | +0.318                | -               | <u>+0.577</u>       | 1.000         |               |              |                    |                    |                  |                   |                  |
| FlushN      | <u>+0.367</u> | +0.289        | <u>-0.497</u> | -                     | -               | -                   | +0.338        | 1.000         |              |                    |                    |                  |                   |                  |
| Cyano.      | -             | -             | <u>-0.528</u> | -                     | -               | <u>+0.347</u>       | <u>+0.530</u> | <u>+0.514</u> | 1.000        |                    |                    |                  |                   |                  |
| Oligochaete | -             | <u>+0.510</u> | <u>+0.530</u> | -0.305                |                 | <u>-0.752</u>       | <u>-0.683</u> | -0.316        | -0.421       | 1.000              |                    |                  |                   |                  |
| Insecticide | -0.269        | -             | -             | -                     | -               | -                   | -             | -             | +0.334       | 1.000              |                    |                  |                   |                  |
| Herbicide   | -0.325        | -             | -             | -                     | +0.292          | -                   | -             | -             | -            | -                  | 1.000              |                  |                   |                  |
| Molluscide  | -0.322        | -             | -             | <u>+0.364</u>         | -               | -                   | -             | -             | -0.293       | +0.282             | -                  | 1.000            |                   |                  |
| Pesticide   | <u>-0.356</u> | -             | -             | -                     | -               | -                   | -             | -             | +0.337       | -                  | -                  | -                | 1.000             |                  |

Note: Levels of significance of the correlations:  $r = 270$ ,  $p = 0.10$   $r = 0.339$ ,  $p = 0.05$ ;  $r = 0.425$ ,  $p = 0.01$  ( $n = 32$ ).

Correlation coefficients with  $p < 0.15$  are not presented; those with  $p < 0.05$  are underlined, those with  $p < 0.01$  are in bold.

The upper right area of the table presents correlations with pesticide use expressed as ai applied per hectare during the two crops of the biological survey, the lower left area presents correlations with pesticide use expressed as cost per hectare of pesticide applied during the two crops of the biological survey and the five preceding crops.

negatively with the C/N ratio of the soil (Table 11.8) indicating that neutral to slightly alkaline soils with a well-decomposed organic matter might have a larger microbial biomass than acidic soils with a less decomposed organic matter. The weak correlations between flush-N, available-N, and total N confirmed that total N is not the best index of N-fertility of wetland soils (Watanabe, De Datta, and Roger, 1988).

Among the 270 individual coefficients of correlation between flush-N and pesticide use, only five indicated a significant correlation at  $p < 0.05$ . This was observed for

- Flush-N in the 0–2 cm soil layer at the beginning of the WS with the quantity of ai of insecticide applied during (1) the previous DS ( $r = 0.353$ ;  $p < 0.05$ ), and (2) the DS and WS of the soil survey ( $r = 0.389$ ;  $p < 0.03$ ).
- Average flush-N value in the 0–2 cm soil layer with the quantity of ai of insecticide applied during the DS ( $r = 0.374$ ;  $p < 0.04$ ).
- Flush-N in the 2–10 cm soil layer at the beginning of the DS with the quantity of ai of (1) insecticide applied during the *next* (!) WS ( $r = 0.421$ ;  $p < 0.05$ ), and (2) herbicide applied during the previous DS ( $r = -0.501$ ;  $p < 0.01$ ).

The four correlations between flush-N and insecticide were positive, while the correlation with herbicide was negative.

Positive correlations between insecticide use and microbial biomass in the upper soil layer are in agreement with the known positive effect of insecticides on microalgae, in relation with grazer control. A negative effect of herbicides is in agreement with their possible inhibitory effect on both microalgae and microflora (see chapter 10). However, the very low number of significant individual correlations (less than 3 percent) and the absence of significant correlations between aggregated/selected data (Table 11.8) indicate that effects were rather incidental and not long lasting or not strong enough to be established with the method of estimation of microbial biomass.

(3) *Cyanobacteria*: Roger, Santiago-Ardales, Reddy, and Watanabe (1987b) reported positive correlations between N<sub>2</sub>-fixing cyanobacteria populations and soil pH and available P content in a large sample of 102 rice soils. In this study, cyanobacteria showed no correlation with soil pH or available P (Table 11.8) probably because of the relatively narrow range of pH of the soils (most of the soils pH were between 5.8 and 6.5) and their relatively high available P content. The correlation between cyanobacteria and available-N ( $r = 0.530$ ) and flush-N ( $r = 0.514$ ) may indicate that cyanobacteria contribute to N-fertility even in soils receiving N-fertilizers. A significant negative correlation ( $r = -0.421$ ,  $p > 0.02$ ) was found between aquatic oligochaete populations and cyanobacteria (Table

11.7), which may reflect the burrowing action of aquatic oligochaetes on organic material accumulating at soil surface (Grant and Seegers, 1985).

Among the seventy-five individual coefficients of correlation between cyanobacteria abundance and pesticide use that were calculated, only five significant values ( $p < 0.05$ ) were observed. This was for

- Populations of cyanobacteria at the beginning of the WS with the quantity of ai of (1) insecticide applied during the previous DS ( $r = 0.410$ ;  $p < 0.02$ ), (2) pesticide applied during the previous DS ( $r = 0.440$ ;  $p < 0.01$ ), and (3) insecticide applied during the DS and WS of the soil survey ( $r = 0.374$ ;  $p < 0.04$ ).
- Populations of cyanobacteria at the end of the DS with the quantity of ai of (1) herbicide applied during the previous DS ( $r = 0.507$ ;  $p < 0.01$ ), and (2) pesticide applied during the previous DS ( $r = 0.448$ ;  $p < 0.015$ ).

In addition positive correlations with a level of significance between 0.05 and 0.10 were found for

- The total quantity of ai of insecticide applied during the DS and WS of the soil survey and (1) populations of cyanobacteria at the beginning of the WS, (2) populations at the end of the DS,
- Average populations of cyanobacteria and total ai of insecticide applied during the DS and WS of the soil survey.

Correlations between aggregated/selected data (Table 11.8) showed a significant effect of insecticides (and to a lesser extent total pesticides) estimated as ai applied during the DS and WS of the soil survey. But these correlations were not significant when pesticide use was estimated from the cost over the last seven cropping seasons. Both methods of estimation of pesticide use indicated an inhibitory effect of molluscicides.

These results partly confirm a positive (but not strongly marked) effect of insecticides on populations of cyanobacteria (see chapter 10). Data on molluscicide seems to indicate an inhibitory effect of the formulations applied, but, because of the restricted number of farms where molluscicide was used, such data need further confirmation.

(4) *Aquatic oligochaetes*: The abundance of aquatic oligochaetes was positively correlated with C and N content in soil, and negatively with bulk density (Table 11.8). The first correlation is in agreement with the observation that organic matter incorporation increases aquatic oligochaete populations (Roger and Kurihara, 1991). The negative correlation with bulk density most probably reflects the requirement of aquatic oligochaetes for wet soils rather than their

mechanical effect on soil. In drying soils, no aquatic oligochaetes were usually recorded in the 10 first centimeters of soil. The negative correlation between aquatic oligochaete and flush-N could be a correlation at the second level resulting from (1) the negative correlation between aquatic oligochaetes and bulk density, and (2) the positive correlation between bulk density and flush-N. However, the hypothesis of a decrease of microbial populations by a direct or indirect action of aquatic oligochaetes cannot be rejected. In particular, aquatic oligochaetes were negatively correlated with cyanobacteria, which were highly correlated with flush-N.

Among the seventy-five individual coefficients of correlation between aquatic oligochaetes abundance and pesticide use, eight significant values ( $p < 0.05$ ) were observed. This was for

- Populations at the end of the WS with (1) the number of pesticide applications ( $r = 0.436$ ;  $p < 0.014$ ), (2) the total quantity of ai of pesticide applied during the previous DS ( $r = 0.424$ ;  $p < 0.017$ ), (3) the total quantity of ai of insecticide ( $r = 0.354$ ;  $p < 0.05$ ), (4) the number of pesticide applications ( $r = 0.443$ ;  $p < 0.012$ ), and (5) the total quantity of ai of pesticide applied during the DS and WS of the soil survey ( $r = 0.431$ ;  $p < 0.015$ ).
- Populations at the end of the DS with the quantity of ai of molluscicide applied during the previous DS ( $r = 0.440$ ;  $p < 0.037$ ).
- Average populations during the survey with (1) the quantity of ai of herbicide applied during the DS ( $r = 0.400$ ;  $p < 0.024$ ), (2) the number of pesticide applications during the DS ( $r = 0.392$ ;  $p < 0.027$ ), and (3) the number of pesticide applications during the DS and WS of the soil survey ( $r = 0.408$ ;  $p < 0.02$ ).

In addition, correlations with a level of significance between 0.05 and 0.10 were found for average populations and the quantity of ai of pesticide applied during (1) the DS ( $r = 0.339$ ;  $p < 0.062$ ), and (2) the DS and WS of the soil survey ( $r = 0.339$ ;  $p < 0.062$ ).

Correlations between aggregated/selected data (Table 11.8) showed only correlations at levels lower than  $p < 0.05$ .

All correlations with pesticide use were positive whereas previous experiments rather indicated a possible negative effect of pesticides, especially insecticides. In fact there was a high chance for correlations observed to be spurious. The quantity of insecticide, herbicide and total pesticide applied were, by accident, negatively correlated with bulk density (Table 11.8) whereas aquatic oligochaetes were strongly negatively correlated with bulk density. Positive correlation between herbicide application and total N and C/N of the soil, and between populations of aquatic oligochaetes and total N and C/N might have



also contributed to a spurious positive correlation between pesticide application and populations of aquatic oligochaetes.

*Other Approaches.* A second approach was to study the level of significance of the difference between average biological values in farms where selected pesticides were or were not used. The *t* test of Pearson applied on normalized data was utilized. Only pesticide used or not used by more than five farmers were tested. None of the sixty tests performed indicated a significant difference.

#### 11.4. Conclusion

Field experiments under controlled conditions were conducted at rates of agrochemicals currently used in farmers' fields. Survey was conducted in fields where farmers applied their usual practices.

Soil microbial biomass, estimated through flush-N measurements, was studied in two experiments in controlled plots and in the farmers' field survey. Data did not show any significant effect of pesticides on a short- or long-term basis. However, caution is needed when interpreting these results because of the high variability of flush-N measurements and the limited knowledge on the significance of the method.

N<sub>2</sub>-fixing cyanobacteria were enumerated in all experiments and the field survey. A few individual observations in field experiments showed a positive effect of insecticide application in plots where N-fertilizer was not broadcast in the floodwater. In the field survey, a weak correlation ( $0.10 > p > 0.05$ ) between cyanobacteria abundance and the quantity of ai of insecticide applied was also found. These results are in agreement with published data reporting a positive effect of insecticides on cyanobacteria through grazer control, but they indicate effects less marked than in many experiments where pesticide levels higher than the recommended dose applied in the absence of N-fertilizer were often used (see chapter 10).

Primary production in the floodwater, studied in two experiments in controlled plots, was also favored by insecticide application. This effect was limited to the early stage of the crop cycle. This observation was in agreement with result of the farm survey showing a weak positive correlation ( $p < 0.10$ ) between soil available-N and insecticide application.

Intensive sampling in experimental plots showed that N-fertilizer and the presence of rice plant affected more floodwater biology than pesticides do. In particular, N-fertilizer broadcasting had a clear stimulatory effect on floodwater primary productivity, favoring the growth of unicellular algae, which resulted in the proliferation of algivorous aquatic arthropods. Pesticides had no long-lasting

effects on these organisms when considered at the crop cycle level. No pesticide effect was usually observed on zooplankton in the presence of broadcast N-fertilizer. In plots where no N-fertilizer was applied, significant effects on zooplankton were observed, but they were incidental and limited. However, in farmers' fields, pesticides are usually not used in the absence of fertilizer.

Aquatic oligochaetes exhibited a significant negative response to pesticide application in three of the four crop cycles studied in experimental plots. Field surveys did not confirm a long-term negative effect of pesticide use on these populations. However, aquatic oligochaetes seems to be a most sensitive indicator of pesticide effect in wetland soils than aquatic arthropods,  $N_2$ -fixing cyanobacteria and soil microbial biomass. The hypothesis that pesticide use, by reducing oligochaete populations, might reduce the translocation of recycled nutrients accumulating at the soil-water interface into the deeper soil was not confirmed by flush-N measurements in the deeper soil layer.

The results summarized in this chapter seem to confirm the common belief that pesticides applied at recommended levels and intervals in ricefields are seldom deleterious to the beneficial microorganisms, invertebrates, and their activities.

In the intensive surveys in experimental plots, only a low percentage of measurements performed at individual sampling times indicated statistically significant differences attributable to pesticide use (Tables 11.2 and 11.5). In the field survey aiming at identifying long-term effects of pesticides significant correlations were relatively less numerous than in experimental plots. Among 420 individual correlations between pesticide use and biological variables tested, only eighteen (4.3 percent) were significant at  $p < 0.05$ . Among twenty-four correlations between aggregated/selected data (Table 11.8) one was significant at  $p < 0.05$  and eight were significant at  $0.10 > p > 0.05$ . Among those, six were doubtful because of a few artificial correlations between pesticide use and soil properties.

Significant effects of pesticides on measured biological variables were not frequent, not very marked—except for aquatic oligochaetes—and not long lasting. However, because of the variety of pesticide used by farmers, the two methods of estimation of pesticide use intensity utilized in the soil survey were biased, and caution is needed when interpreting the results. In addition, results presented are fragmentary, and more detailed studies are definitely needed before drawing conclusions on the long-term effects of pesticide use on microorganisms and invertebrate populations in ricefields. Data presented raise the problem of the methodological approach to assess these effects. In particular, the results of the field survey demonstrate the limitations of studies performed under realistic but uncontrolled conditions and the need for long-term trials in experimental fields.

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## Notes

I. As indicated on the package. Indeed, the authors disagree with the utilization of tablespoons for preparing pesticide solutions.

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# 12 THE IMPACT OF PESTICIDES ON FARMER HEALTH: A MEDICAL AND ECONOMIC ANALYSIS IN THE PHILIPPINES<sup>1</sup>

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Prolonged exposure to pesticides can lead to cardiopulmonary disorders, neurological and hematological symptoms, and skin disease (Davies, Freed, and Whittemore, 1982; Smith, Carpenter, and Faulstich, 1988). These symptoms can lower productivity because of the farmer's absence from work during treatment and recuperation and impaired capacity to work. Farmers who do not know about the harmful effects of pesticides sometimes overvalue their benefits and use them beyond the private and social optimum levels.

In this unique study, an economist and a medical doctor jointly assessed the impact of prolonged pesticide use on farmer health. The study objectives were to identify the types of health impairments caused by long-term pesticide use and to quantify the impairment relative to the level of pesticide use. Detailed medical examinations showed that pesticide users exhibited symptoms of long-term exposure to hazardous chemicals. Econometric analysis showed that the magnitude of chronic health effects and health costs were directly related to pesticide exposure. When health effects were explicitly accounted for, the net benefits of insecticide use were negative.



## 12.1. Methodology and Data Description

Two samples of farmers with long-term exposure to pesticides in rice production were compared with a sample of farmers with no history of pesticide exposure. All farmers were given a medical assessment that included an interview, physical examination, a battery of laboratory tests, and exposure history. A set of medical indices of pesticide exposure were defined, and the exposed and control groups were compared. Medical indices were related econometrically (using logit regressions) to a set of pesticide-use indicators obtained from farm monitoring. Probabilities of health risk were assessed relative to differential levels of pesticide use, differences in types of chemicals used, and farmer characteristics. The strength of this design lies in its ability to detect chronic and subacute effects. Its weakness lies in its inherent bias for survivors.

### 12.1.1. *The Pesticide User Sample (the Exposed Group)*

A sample of thirty-one farmers and twenty-five pesticide applicators from Laguna and forty-two farmers and fifteen pesticide applicators from Nueva Ecija comprised the exposed group. Laguna farmers were moderate users; Nueva Ecija farmers were heavy pesticide users. Both groups of farmers had documented exposure to pesticides (particularly organophosphorous compounds) for fifteen to twenty-five years. These farm households were intensively monitored for all inputs and technologies, and special emphasis was placed on practice of pest management, including safety practices used to handle pesticides. A profile of the pesticide use practices of this group is provided in Chapter 3.

### 12.1.2. *The Nonuser Sample (the Control Group)*

A sample of thirty-nine farmers were chosen from Lucban, Quezon, a rainfed production area where pesticide use for rice is not common. The farm households in the control group had lower total incomes than the exposed group but lived in similar socioeconomic conditions and used similar agricultural practices. The intensity of rice production in this area is lower than in Laguna and Nueva Ecija; farmers usually get only one crop per year and use lower levels of fertilizers and other inputs. Rice pest pressure is lower, and, therefore, the rice area is generally pesticide-free.

All fifty-six Laguna, thirty-nine Quezon, and fifty-seven Nueva Ecija respondents were brought to the medical clinic at the International Rice Research Institute (IRRI) for a detailed baseline medical assessment.<sup>2</sup> The assessment included a detailed physical and laboratory examination of each farmer

Table 12.1. Hypothesized Health Effects of Chronic Exposure to Pesticides

| <i>System</i>                       | <i>Effects</i>        | <i>Critical Signs<br/>and Symptoms/<br/>Laboratory Findings</i> | <i>Source</i>                                        |
|-------------------------------------|-----------------------|-----------------------------------------------------------------|------------------------------------------------------|
| Eye                                 | Pterygium             | Vascular membrane on the eye, decreased visual acuity           | Verbal communication with ophthalmologist            |
| Skin                                | Eczema                | Lichenification and fissuring                                   | Morgan, 1982                                         |
|                                     | Nail destruction      |                                                                 | FPA findings                                         |
| Respiratory<br>(pulmonary)<br>tract | Bronchial asthma      | Wheezing, cough<br>brochospasm dyspnea                          | Hock, 1987<br>Morgan, 1982<br>Nemery, 1987           |
|                                     | cardiovascular system | ECG changes, high blood pressure                                | Morgan, 1982                                         |
| Gastrointestinal tract              | Chronic gastritis     | Epigastric pain, nausea, vomiting                               | WHO, 1986                                            |
| Neurologic system                   | Polyneuropathy        | Motor weakness, sensory deficit, hypo/areflexia                 | Hayes, 1982<br>Hock, 1987<br>Ragsdale and Kuhr, 1987 |
|                                     |                       |                                                                 |                                                      |

plus a documentation of personal health history and habits (especially drinking and smoking). Periodic health monitoring of the Laguna and Nueva Ecija farmers was conducted during the study to identify changes in farmers' health, especially in relation to pesticide use.

## 12.2. Health Problems and Long-Term Exposure to Pesticides

Chronic health effects are associated with prolonged pesticide exposure (Table 12.1).

### 12.2.1. Eye Effects

The eye is very vulnerable to physical and chemical hazards in agriculture. Some pesticides, such as 2,4-D and acetamides, are known eye irritants (Morgan,

1977). Laguna and Nueva Ecija farmers have been using acetamides and 2,4-D for at least five years. A chronically irritated eye can form pterygium, a vascular membrane over the cornea, that usually affects older people and people exposed to dust and wind. As severity increases, the vascular membrane may encroach on the pupil and diminish visual acuity. Surgery is required to improve eyesight. Initially pterygium can reduce farmers' productivity because of bothersome symptoms. Later, diminished vision reduces productivity.

### 12.2.2. *Skin Effects*

Pesticides enter the body mainly through the skin and not, contrary to common belief, through the respiratory tract. The mixing and transferring of concentrates poses a greater health hazard to farm workers than the application of pesticides. For spray operators, dermal exposure levels were higher than inhalation levels. The degree of contamination is proportional to the concentration of the chemical and the proximity to the source of emission (Hamilton, 1982). Spraying or dusting of pesticides leave on exposed skin residues that are about 20 to 1,700 times the amount that reaches the respiratory tract. The quantity varies with working conditions, application techniques, protective equipment, and duration of exposure (Bainova, 1982).

Dermal contamination is greater when a knapsack sprayer is used than when a spinning disc applicator or an electrodyn sprayer is used (Durand, Pascoe, and Bingham, 1984). The hands and forearms have the highest potential for pesticide contamination (Castañeda, Maramba, and Ordas, 1990; Zweig et al., 1985).

Among the pesticides used by the rice farmers, 2,4-D, organochlorines, and acetamides are mild to moderate skin irritants and potential sensitizers (Morgan, 1977). Eczema, a chronic allergic dermatitis characterized by lichenification and fissuring, is a dermatologic health indicator of pesticide exposure. The skin appears thickened and has accentuated markings. Other health indicators are the destruction of the distal portions of the toe nails, which gives them an "eaten-up" appearance.

### 12.2.3. *Respiratory Tract Effect—*

Long-term exposure to chemical irritants such as pesticides can cause respiratory symptoms such as cough, cold, sputum formation, wheezing, rales, tenderness, and decreased chest expansion (Hock, 1987; Morgan, 1982; Nemery, 1987). Incipient lung disorders can be detected by a thorough physical examination and adequate medical history. Bronchial asthma and other abnormal lung findings are two respiratory tract indicators of pesticide exposure.

#### 12.2.4. *Cardiovascular Effects*

In acute pesticide poisoning, the heart can be damaged either by direct action on the myocardium or by the effects of low tissue oxygenation. Hardening of blood vessels causes elevation of blood pressure. High blood pressure was noted among pesticide handlers in a health survey conducted in seven formulating plants in the Philippines (Maramba, personal communication, Manila, Philippines). Therefore, one health indicator is elevated blood pressure.

Organophosphates and 2,4-D have been implicated as causes of myocardial injury and injury to the conducting system, that are reflected in electrocardiogram (EKG) changes (Morgan, 1977).

#### 12.2.5. *Gastrointestinal Tract Effects*

Pesticides usually accidentally enter the gastrointestinal tract through the mouth. For example, a farmer who is applying pesticides and who smokes or wipes sweat off near the mouth may unknowingly ingest pesticide particles. Carbamate insecticides formulated in methyl alcohol and ingested can cause severe gastroenteritic irritation (Morgan, 1977). Given in large doses to experimental animals, 2,4-D and organochlorines are moderately irritating to the gastrointestinal lining and cause vomiting, diarrhea, and mouth ulcers (Morgan, 1977). Organophosphates and copper salts also irritate the gastrointestinal tract, and irritations are manifested as intense nausea, vomiting, and diarrhea. The health indicator chronic gastritis is clinically characterized by epigastric tenderness and pain associated with nausea and vomiting.

#### 12.2.6. *Neurological Effects*

Organophosphorous compounds and 2,4-D are neurotoxicants (Morgan, 1977). Both have been implicated as causative agents for polyneuropathy, a neurologic disorder that manifests typically as motor weakness in the distal muscles and sensory deficit with a "glove-and-stocking" distribution (Braunwald, 1987). Absence of deep tendon reflexes in the early stages may be the only sign, but neuropathy may be purely motor or purely sensory.

Diabetes is highly prevalent in the Philippines and must be considered in the differential diagnosis of polyneuropathy. Isolated hyporeflexia, another neurologic index, is a known sensitive indicator of chronic exposure to organophosphorous pesticides (WHO, 1990).

Table 12.2.    Prevalence of Health Impairments per Organ System Among Quezon, Laguna, and Nueva Ecija Farmers

| <i>Effect Parameters<br/>(Health Indicators)</i>                  | <i>Quezon<br/>Control<br/>39</i> |                    | <i>Laguna<br/>Exposed<br/>56</i> |                    | <i>Nueva Ecija<br/>Exposed<br/>57</i> |                    |
|-------------------------------------------------------------------|----------------------------------|--------------------|----------------------------------|--------------------|---------------------------------------|--------------------|
|                                                                   | <i>Number</i>                    | <i>%*</i>          | <i>Number</i>                    | <i>%</i>           | <i>Number</i>                         | <i>%</i>           |
| Eye (pterygium)                                                   | 4                                | 10.25 <sup>a</sup> | 14                               | 25.00 <sup>b</sup> | 38                                    | 66.67 <sup>c</sup> |
| Dermatologic system<br>(nail pitting, eczema)                     | 0                                | 0.00 <sup>a</sup>  | 8                                | 14.29 <sup>b</sup> | 26                                    | 45.61 <sup>c</sup> |
| Respiratory system<br>(bronchial asthma,<br>abnormal PE findings) | 9                                | 23.07 <sup>a</sup> | 27                               | 48.21 <sup>b</sup> | 26                                    | 45.61 <sup>b</sup> |
| Cardiovascular system<br>(elevated BP, EKG)                       | 18                               | 46.20 <sup>a</sup> | 28                               | 50.00 <sup>a</sup> | 28                                    | 49.12 <sup>a</sup> |
| Gastrointestinal tract (GIT)<br>(chronic gastritis)               | 0                                | 0.00 <sup>a</sup>  | 32                               | 57.14 <sup>b</sup> | 5                                     | 8.77 <sup>a</sup>  |
| Polyneuropathy                                                    | 0                                | 0.00 <sup>a</sup>  | 3                                | 5.36 <sup>ab</sup> | 6                                     | 10.53 <sup>b</sup> |

Note: Percentages followed by the same letter are not significantly different at 0.05 level of significance.

**12.3.    Evidence of Health Impairments Because of Pesticide Exposure**

*12.3.7.    Eye Effects*

Because the farmers in the Quezon group were older, more cases of pterygium (perhaps unrelated to pesticides) were expected than in Laguna and Nueva Ecija. Contrary to expectations, more cases were found in both Laguna (25 percent) and Nueva Ecija (66.67 percent) than in Quezon (10.55 percent) (Table 12.2). Pesticide-related pterygium, although not specifically recounted in available literature, can arise from pesticide irritation of the conjunctivae. The incidence of eye abnormalities increased significantly with age and with exposure to category I and II chemicals (Table 12.3).

The probability of eye abnormalities among the sample households is 0.36; this was determined from the logit function at the mean levels of all variables (Figure 12.1). An increase in the application of category I and II chemicals, from the mean level of one per season to two, increased the probability of eye problems

Table 12.3. Logit Regressions on Health Impairments

|                                                         | <i>Eye</i>            | <i>Pulmonary</i>     | <i>Polyneu-<br/>ropathy</i> | <i>Skin</i>            | <i>Gastro-<br/>intes-<br/>tinal</i> | <i>Multiple<br/>Impair-<br/>ments</i> |
|---------------------------------------------------------|-----------------------|----------------------|-----------------------------|------------------------|-------------------------------------|---------------------------------------|
| Intercept:                                              |                       |                      |                             |                        |                                     |                                       |
| Alpha 1                                                 | -3.2373**<br>(1.391)  | -2.8914**<br>(1.464) | -5.8633*<br>(3.4546)        | -6.7327***<br>(1.6778) | 4.3077<br>(1.95)                    | 0.0493<br>(1.2267)                    |
| Alpha 2                                                 |                       |                      |                             |                        |                                     | -1.0807<br>(1.2287)                   |
| Alpha 3                                                 |                       |                      |                             |                        |                                     | -2.5382**<br>(1.2462)                 |
| Alpha 4                                                 |                       |                      |                             |                        |                                     | -4.8817***<br>(1.3183)                |
| Age                                                     | 0.0455***<br>(0.0144) | 0.0501***<br>(0.015) | 0.0508<br>(0.0323)          | 0.0218<br>(0.0162)     | -0.0443***<br>(0.0159)              | 0.0237*<br>(0.0125)                   |
| Weight/<br>height                                       | -0.00174<br>(0.049)   | -0.0263<br>(0.0488)  | -0.0708<br>(0.1186)         | 0.151***<br>(0.057)    | -0.1851**<br>(0.0780)               | -0.0354<br>(0.0419)                   |
| Smoking                                                 | -                     | 0.6350*<br>(0.3972)  | -                           | -                      | -                                   | 0.6116*<br>(0.3533)                   |
| Drinking                                                | -                     | -                    | 1.9852*<br>(1.1394)         | -                      | -                                   | -0.7123<br>(0.3575)                   |
| Total dosage<br>of category I<br>and II<br>pesticides   | 0.3497**<br>(0.1714)  | 0.259*<br>(0.1566)   | -0.1025<br>(0.2967)         | 0.2180<br>(0.1546)     | 0.0919<br>(0.1695)                  | 0.3551***<br>(0.1363)                 |
| Total dosage<br>of category<br>III and IV<br>pesticides | 0.4986<br>(0.3942)    | 0.0291<br>(0.3918)   | 1.3815*<br>(0.7131)         | 1.0414**<br>(0.4267)   | 0.9849**<br>(0.4348)                | 0.9616***<br>(0.3421)                 |
| Cloth cover<br>over mouth                               | -                     | 0.3833<br>(0.4106)   | -                           | -                      | -                                   | 0.6309*<br>(0.3487)                   |
| n                                                       | 148                   | 145                  | 148                         | 148                    | 149                                 | 145                                   |
| Chi-square                                              | 19.849                | 15.7                 | 8.885                       | 22.516                 | 24.157                              | 36.293                                |

Note: Figures in parentheses are standard errors of estimate.

\*\*\*, \*\*, \* denote significance at the 1, 5 and 10 percent levels, respectively.

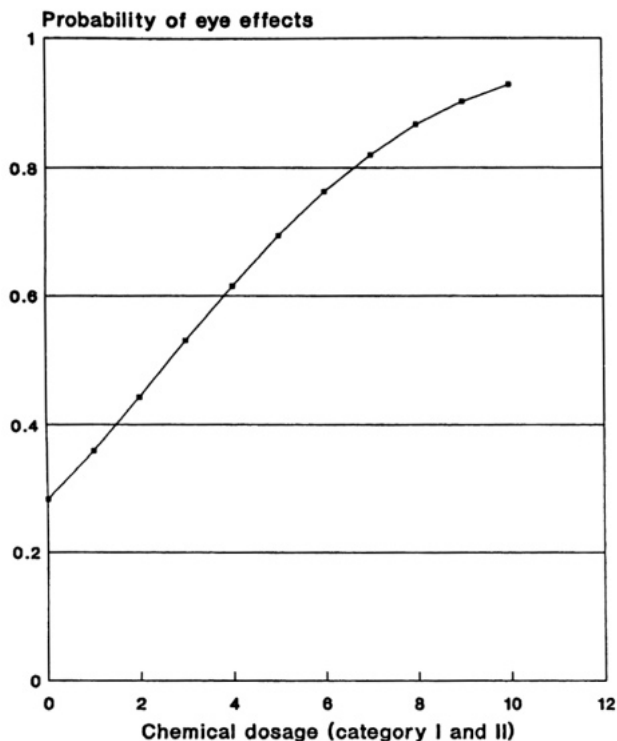


Figure 12.1. Pesticides and Eye Effects

by 22 percent. Farmers who applied three recommended doses of category I and II pesticides had a probability of 0.53 of having chronic eye problems.

### 12.3.2. Skin Effects

Almost half (45.61 percent) the farmers from Nueva Ecija showed dermal impairment compared with 14 percent from Laguna and none from Quezon (Table 12.2). One-third (36.84 percent) of Nueva Ecija farmers, but none from Laguna and Quezon, exhibited nail destruction. This may be because organotin compounds were used as molluscicides. Snails pose a major threat in Nueva Ecija (Warburton and Pingali, 1993). Organotins were banned in the Philippines and farmers replaced it with endosulfan, an insecticide. Eventually, endosulfan was prohibited for snail control because it was not registered for this use.

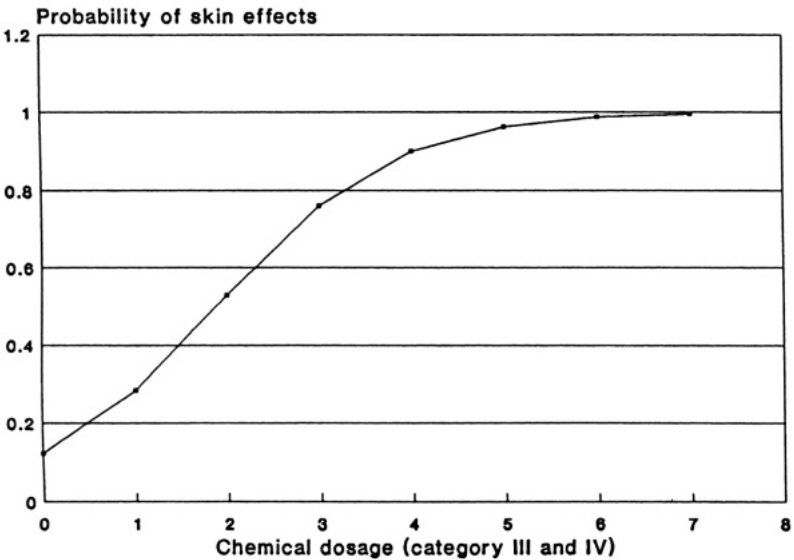


Figure 12.2. Pesticides and Skin Effects

The incidence of skin effects was positively related to the use of pesticides, although only category III and IV chemicals were significant (Table 12.3). This is because most acetamides are classified as category IV compounds, and unprotected use of these chemicals is known to cause skin problems. Acetamides are popular herbicides in Laguna and Nueva Ecija.

Farmers of average age and nutritional status who did not apply any herbicides (category II and IV chemicals) had a probability of 0.12 of having skin problems. The probability of skin problems rose to 0.30 for farmers who applied one herbicide dose and to 0.50 for farmers who applied two herbicide doses (Figure 12.2).

12.3.3. *Respiratory Tract Effects*

Abnormal respiratory findings were significantly more prevalent in Laguna (48 percent) and Nueva Ecija (45 percent) than in Quezon (23 percent) (Table 12.2) and were significantly higher for the exposed group even after smoking was accounted for as a confounding factor. The incidence of respiratory abnormalities was significantly related to age, smoking, and the use of category I and II pesticides. Evaluated at the sample mean, the probability of respiratory



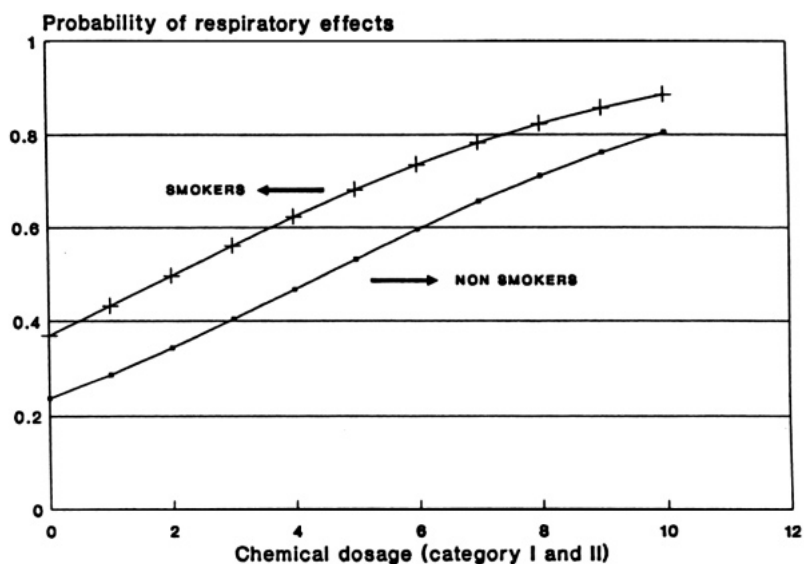


Figure 12.3. Pesticides and Respiratory Effects

abnormalities in farmers who did not smoke was 0.30 (Figure 12.3). These farmers applied one recommended dose each of category I and II and category III and IV chemicals. At this level of pesticide use, farmers who smoke had a 50 percent higher probability of respiratory abnormalities. The probability of respiratory problems increased by 17 percent for farmers who applied two doses of insecticides (category I and II chemicals) and by 38 percent for farmers who applied three doses, irrespective of their smoking habits.

#### 12.3.4. Cardiovascular Effects

There was no significant difference in the results of the EKGs among the farmers at the three sites (Table 12.2). Differences in age and drinking habits adversely affect cardiovascular outcomes and can confound results.

To unmask confounding, the data were stratified for drinking and age. When age was held constant, nobody under forty years of age in Quezon had an abnormal EKG, but 29 percent in Laguna and 39 percent in Nueva Ecija were abnormal. Normally, EKG changes are more prevalent among people over forty. When drinking was held constant, 7 percent in Laguna and 11 percent in Nueva Ecija had functional EKG impairments, but nobody did in Quezon. When

stratified by sex, all but two cases of cardiac abnormalities were males. Because young males generally apply the pesticides, they face an abnormally higher risk of cardiac problems than older males. No significant difference in blood pressure elevation between the two groups was reported.

### ***12.3.5. Polyneuropathy***

Nobody in Quezon, 5 percent in Laguna and 10 percent in Nueva Ecija had polyneuropathy. There was a significant difference between the results from Quezon and Nueva Ecija. When drinking was taken into account, 8 percent of farmers from Nueva Ecija, but none from Laguna and Quezon, had polyneuropathy. The incidence of polyneuropathy was significantly associated with drinking and with pesticide use (Table 12.3). Category III and IV pesticides had a significant positive effect.

Farmers who did not drink alcohol were evaluated at the sample mean with respect to age, nutritional status, and the application of pesticides. They had a probability of 0.02 for positive findings of polyneuropathy. The probability rose by 532 percent for farmers who regularly consumed alcohol.

### ***12.3.6. Gastrointestinal Effects***

Farmers in Laguna had a significantly higher incidence of gastrointestinal problems compared with the farmers in Quezon and Nueva Ecija (Table 12.2). The incidence of gastrointestinal problems was positively related to pesticide use, and the use of category III and IV chemicals was significant (Table 12.3). Gastrointestinal problems had a significant negative relationship with nutritional status. The significant negative effect of age was unexpected. Farmers evaluated at the sample mean who applied one recommended dose of category III and IV chemicals had a probability of 0.27 of an abnormal gastrointestinal finding. Two recommended doses of the same chemicals increased the probability by 85 percent and three doses increased it by 167 percent.

### ***12.3.7. Incidence of Multiple Health Impairments***

The initial analysis attempted to isolate the impact of pesticides on each specific illness. However, farmers with long-term pesticide exposure face several illnesses at the same time. Pesticides may also cause other nonspecific illnesses. Seventy-nine percent of the control group had two pesticide-related impairments or less; whereas 78.5 percent of Laguna farmers and 82.5 percent of Nueva Ecija

Tabl 12.4.    Frequency of Farmers with Positive Health Index at Three Locations

| <i>Number of Positive<br/>Health Index</i> | <i>Quezon</i> |          | <i>Laguna</i> |          | <i>Nueva Ecija</i> |          |
|--------------------------------------------|---------------|----------|---------------|----------|--------------------|----------|
|                                            | <i>Number</i> | <i>%</i> | <i>Number</i> | <i>%</i> | <i>Number</i>      | <i>%</i> |
| 0                                          | 3             | 5.3      | 1             | 1.79     | 0                  | 0.00     |
| 1                                          | 23            | 40.4     | 4             | 7.14     | 3                  | 5.26     |
| 2                                          | 19            | 33.3     | 7             | 12.5     | 7                  | 12.28    |
| 3                                          | 10            | 17.5     | 19            | 33.93    | 16                 | 28.07    |
| 4                                          | 2             | 3.5      | 14            | 25.00    | 18                 | 31.58    |
| 5                                          |               |          | 11            | 19.64    | 8                  | 14.04    |
| 6                                          |               |          | 0             | 0.00     | 3                  | 5.26     |
| 7                                          |               |          | 0             | 0.00     | 2                  | 3.51     |

farmers had three impairments or more (Table 12.4). The maximum number of health impairments in the Quezon group was four; in the Laguna group, five; and in the Nueva Ecija group, seven.

The incidence of multiple health impairments was significantly and positively related to age, smoking habits, and the use of both of category I and II and category III and IV pesticides. The use of a cloth cover over the mouth and nose, a common practice during spraying, had an unexpected positive significance. This suggests that, although farmers believe it provides them protection, the use of this cover actually creates more problems because it absorbs chemicals and the farmer inhales through this concentrated film of chemicals.

For nonsmoking farmers who apply one recommended dose of pesticides, the probability of being affected by at most three illnesses at the same time is 0.19. An additional dose of category I and II chemicals increases this probability by 37 percent. Farmers who smoke have a 63 percent greater probability of at most three health impairments.

**12.4.    A Reassessment of the Costs and Benefits of Pesticide Use**

*12.4.1.    Valuation of the Health Cost of Pesticide Exposure*

The costs faced by farmers because of health impairments was calculated on the basis of the medical tests. The medical tests provided an assessment of each

Table 12.5. Estimated Health Cost Function for Farmers Exposed to Pesticides (Dependent Variable Is Log of Health Cost)

| <i>Independent Variables</i>                   |                       |
|------------------------------------------------|-----------------------|
| Intercept                                      | 4.366***<br>(1.3900)  |
| Log (age)                                      | 1.192***<br>(0.3130)  |
| Ratio of weight to height                      | -0.0756**<br>(0.0316) |
| Dummy for smoking                              | 0.9160***<br>(0.2360) |
| Dummy for drinking                             | -0.5300**<br>(0.2400) |
| Log (category I and II chemicals)<br>(doses)   | 0.4860**<br>(0.2320)  |
| Log (category III and IV chemicals)<br>(doses) | -0.0420<br>(0.3650)   |

Note: Figures in parentheses are standard errors of estimates.

\*\*\*, \*\* denote significance at the 1 and 5 percent levels, respectively.

farmer-respondent's ailments and their seriousness. These ailments may or may not be related to pesticide exposure. The treatment required to restore the farmer's health was assessed. Treatment costs (including medication and physicians' fees) plus the opportunity cost of farmers' time lost in recuperation was used as a measure of the health cost per farmer. The average health costs were PHP 2890 for farmers exposed to pesticides and PHP 1790 for farmers who were unexposed, a difference of 61 percent.

Health costs from pesticide use are associated with total pesticide use, pesticide exposure (the number of times the farmer comes into contact with pesticides), pesticide hazard category (category I and II pesticides, which include most organophosphates and organochlorines, have a greater health effect than category III and IV pesticides), and other farmer characteristics (weight over height, age, smoking, and alcohol consumption). A log-linear regression was estimated to identify the significance of each of these variables in determining the cost of health impairment.

Category I and II chemicals (insecticides) significantly influenced farmer health costs (Table 12.5). Category III and IV chemicals (herbicides) did not influence health costs. Costs increased by 0.49 percent for every 1 percent increase in insecticide dose. The insignificance of herbicides in the health cost equation could be because of the overwhelming number of insecticide-related illnesses compared with herbicide-related illnesses.

Table 12.6. Net Benefits and Certainty Equivalents of Alternative Strategies of Insecticide Use That Consider Health Costs in Philippine Pesos (PHP)<sup>a</sup>

| <i>Strategy of<br/>Pest Management</i> | <i>Number of<br/>Recommended<br/>Doses</i> | <i>Estimated<br/>Health<br/>Costs</i> | <i>Net<br/>Benefits<sup>b</sup></i> | <i>Certainty<br/>Equivalents<sup>c</sup></i> |
|----------------------------------------|--------------------------------------------|---------------------------------------|-------------------------------------|----------------------------------------------|
| <i>Laguna:</i>                         |                                            |                                       |                                     |                                              |
| Complete protection                    | 6                                          | 2792                                  | 11336                               | 13862                                        |
| Farmers' practice                      | 2                                          | 1849                                  | 12385                               | 15706                                        |
| IPM                                    | 1                                          | 1519                                  | 12208                               | 15791                                        |
| Natural control                        | 0                                          | 1084                                  | 12844                               | 16664                                        |
| <i>Nueva Ecija:</i>                    |                                            |                                       |                                     |                                              |
| Complete protection                    | 6                                          | 2792                                  | 14058                               | 17539                                        |
| Farmers' practice                      | 2                                          | 1849                                  | 14284                               | 18078                                        |
| IPM                                    | 1                                          | 1519                                  | 14227                               | 18109                                        |
| Natural control                        | 0                                          | 1084                                  | 14743                               | 18688                                        |

a. USD 1.00 = PHP 27.50.

b. Yields were estimated from Table 12.7; a price of PHP 4.60 per kilogram was used.

c. Risk aversion coefficient of 1.37 was used.

Weight to height ratio had a significant negative effect on health costs; age and smoking habits increased health costs significantly. The coefficient of the drinking variable, although significant, had a negative sign. Some measurement deficiencies may have influenced this result; that is, some farmers might have stopped drinking because they already had a disease or ailment. In addition, younger and healthier individuals tend to be more candid about drinking habits. This kind of information would reflect a high health cost for a nondrinker respondent in the data set.

The health cost regression results were used to estimate expected health costs per recommended dose of insecticides. The mean cost per insecticide dose (Table 12.5) was based on estimates for a nonsmoking, nondrinking population of farmers. It assumes an average age of forty-four years, a weight to height ratio of 23.5, and an average herbicide dose of 0.50. Four strategies for pest management were evaluated: natural control (no insecticide application), integrated pest management (one recommended dose of insecticides), farmers' practice (two recommended doses of insecticides), and prophylactic control (six recommended doses of insecticides).

When insecticides were not applied, the health costs were on the average PHP 1084; when one recommended dose of insecticide was applied, costs rose to PHP 1519 (Table 12.6). Most farmers usually apply two doses of insecticides.

Table 12.7. First and Second Moment Regression Equations for Irrigated Rice Production (in kg/ha) in Laguna and Nueva Ecija, Philippines (in logarithm)

| <i>Independent Variable</i> | <i>Laguna</i>       |                      | <i>Nueva Ecija</i>  |                      |
|-----------------------------|---------------------|----------------------|---------------------|----------------------|
|                             | <i>First Moment</i> | <i>Second Moment</i> | <i>First Moment</i> | <i>Second Moment</i> |
| Constant                    | 8.12***<br>(0.34)   | 0.77<br>(0.85)       | 5.81***<br>(0.26)   | 0.51**<br>(0.16)     |
| Nitrogen                    | 0.12*<br>(0.08)     | 0.03<br>(0.17)       | 0.49***<br>(0.06)   | -0.06<br>(0.04)      |
| Insecticide dose            | 0.06***<br>(0.01)   | -0.12***<br>(0.02)   | 0.06***<br>(0.01)   | -0.40*<br>(0.02)     |
| Herbicide dose              | -0.12***<br>(0.03)  | 0.18***<br>(0.05)    | -0.04**<br>(0.02)   | -0.03<br>(0.04)      |
| Preharvest labor            | -0.12<br>(0.09)     | -0.16**<br>(0.07)    | 0.09***<br>(0.03)   | -0.01<br>(0.02)      |
| Season dummy <sup>a</sup>   | 0.29***<br>(0.05)   | -0.33***<br>(0.08)   | -                   | -                    |

Note: Figures in parentheses are standard errors of estimate. \*\*\*, \*\*, \* denote significance at the 1, 5, and 10 percent levels, respectively.

a. Season dummy = wet season, dry season.

For them, the health costs were PHP 1849. For farmers who applied a complete package of prophylactic applications, the health costs were PHP 2792.

#### 12.4.2. Valuation of the Net Benefits of Pesticides

Productivity benefits of insecticide and herbicide use, in terms of yield increases, were quantified by estimating production functions for the Laguna and Nueva Ecija samples. The expected effects of pesticides on mean yields and on the variance of yields were determined (see Table 12.7 for the regression results). Insecticides had a significant positive effect on the mean and a significant negative effect on the variance of the yield distribution for both sites.

Productivity benefits were evaluated, first by assuming risk neutrality and then by assuming risk aversion. The latter analysis was done in an expected utility maximization framework. The coefficients of risk aversion were taken from Sillers (1980).

When health costs were explicitly considered for a risk-neutral farmer, the net benefits of insecticides were negative (Table 12.6). In other words, the positive production benefits of insecticides were overwhelmed by the increased

health costs. This is because insecticides have a small positive effect on the mean of the yield distribution compared with the large negative health effect. A farmer who applied two recommended doses of insecticides increased net profits by PHP 277 compared with a farmer who applied only one; however, health costs went up by PHP 330, a net loss of PHP 53. When strategies for pest control were ranked in terms of net benefits (including health costs) indicate that the natural control option (no insecticide application) was the dominant strategy, followed by the current farmers' practice of two applications, and then the IPM strategy. IPM strategy in its current form ranks lower than the farmers' practice because of the high labor requirement to monitor pest populations.

Did the dominance of natural control hold when we considered risk aversion? The pest control strategies were ranked in terms of expected utilities (certainty equivalents). When health costs were explicitly considered, the natural control option was the dominant pest control strategy for both locations (Table 12.6). IPM and farmers' practice did not differ very much, and complete protection came last.

Therefore, the use of more insecticides, especially category I and II chemicals, raised the expected value of health costs. This shifted the net benefit function to the left because health costs increased the total cost of production. After the farmers become aware of the costs associated with pesticide exposure, they increased the threshold levels to determine when to spray.

## 12.5. Conclusions

Farmers and agricultural workers face acute and chronic health effects because of prolonged exposure to pesticides. Eye, skin, pulmonary, and neurologic problems are significantly associated with long-term pesticide exposure. Pesticides that might be linked to these impairments include certain organophosphates, organochlorines, organotins, and phenoxy herbicides. Most of these chemicals, commonly available in the Philippines and across Asia, are classified by the World Health Organization (WHO) as extremely hazardous chemicals (category I and II chemicals) and are either banned or severely restricted for use in the developed world.

Explicitly accounting for health costs substantially raises the cost of using pesticides. The value of crops lost to pests is invariably lower than the cost of treating pesticide-caused diseases. When health costs are considered, the natural control ("do nothing") option is the most profitable and useful strategy for pest control.

The current pesticide pricing and regulatory structure plus inadequate storage, unsafe handling practices, short reentry intervals, and improper sprayer

maintenance create an environment with greater accessibility and increased exposure to chemicals. Regulatory policies that discourage the use of highly hazardous chemicals should be examined, especially in terms of their impact on farmer health and crop losses due to pest damage. Investments in farmer training and in information campaigns on proper pesticide management could help reduce some of the health risks.

## Notes

1. An earlier version of this paper had been published in the *American Journal of Agricultural Economists* 76 (August 1994): 587–592.

2. The medical assessment was carried out by a medical team that consisted of a physician, nurse, X-ray technician, and medical technologist. The nurse interviewed the farmers regarding their personal, family, and occupational histories, including drinking and smoking habits. The doctor performed a complete physical examination on all the farmers using a protocol especially designed for the project. Cholinesterase determinations were done by the medical technologist; chest X-rays and electrocardiograms (EKG) were done by the X-ray technician. The readings for the EKG were done by two cardiologists. The X-rays were read by a radiologist.

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# 13 PESTICIDES, PRODUCTIVITY, AND FARMER HEALTH: A PHILIPPINE CASE STUDY

J.M. Antle and P.L. Pingali

Health is recognized as one of the most important components of the human capital of rural people in developing countries. There is a growing body of literature showing the productivity effects of health associated with nutrition (e.g., Bliss and Stem, 1978; Strauss, 1986; Deolalikar, 1988; Pitt, Rosenzweig, and Hassan, 1990). In this literature, the productivity effects of health are inferred either by correlating health indicators with wages or by including health indicators in an agricultural production function. The human capital literature also has demonstrated that farmer education plays an important role in the allocative and technical efficiency of farmers (Welch, 1970; Schultz, 1975).

This paper presents an approach that integrates aspects of the health and education literatures to study the farm productivity effects of health and the health effects associated with on-farm pesticide use. This approach was implemented in a unique study of rice production and farmer health in two regions of the Philippines. Production data from a farm-level survey were integrated with health data collected from the same population of farmers to measure the impacts of pesticide use on farmer health and the impacts of farmer health on productivity. These relationships were then used in a simulation analysis to investigate the health and productivity tradeoffs implied by a policy to restrict pesticide use.

Pesticides are a significant and growing component of the modern rice technology that has been widely adopted across Asia. While concerns have been expressed for more than a decade about the adverse effects of pesticides on human health and the environment in developing countries (Bull, 1982), and there has been a commitment to sustainable agriculture by the international agricultural research system (Technical Advisory Committee, 1989), there is a need to systematically quantify and assess the health and environmental effects of pesticides at the farm level. The research reported here is a part of a program at the International Rice Research Institute (IRRI) directed toward the assessment of the economic, health, and environmental impacts of pesticides.

Both anecdotal evidence and available data on Philippine farmers' use of pesticides indicate that they do not typically utilize recommended doses nor do they utilize the chemical industry's recommended practices for safe storage, handling, and application (Chapter 3; Rola and Pingali, 1993). There appear to be many reasons for this state of affairs. On the one hand, most small-scale farmers in the Philippines have little or no formal education. While their traditional farming knowledge is adequate for them to benefit from the modern varieties, effective and safe chemical pest management requires knowledge that goes beyond traditional farming practices. A wide and changing array of insecticides, herbicides, and other pesticides are available to farmers, but little if any research and extension is available to guide farmers in their use, and most have not received training for safe storage, handling, and application. Most farmers rely on the recommendations of chemical dealers or their own experience in deciding how to use pesticides. As emphasized by Schultz (1975), farmers with low levels of investment in human capital may be "poor but efficient" under static technological and economic conditions, but are likely to be technically and economically inefficient in a changing environment where the "ability to deal with disequilibria" is important. Thus, human capital theory is consistent with data indicating that Philippine farmers do not use pesticides either efficiently or safely. The farmers represented in this study all used backpack sprayers to apply toxic pesticides, but according to data collected on farmers' practices, none took effective self-protection measures when working in the field with these materials.

This study focuses on two aspects of pesticide productivity: the conventional, direct effect of pesticides used as a production input to control pests; and an indirect human health effect, operating through the chronic effects that pesticide exposure has on farmers' health, and the effects that farmers' health has on farm productivity. Prolonged exposure to pesticides could cause one or more of the following effects: cardiopulmonary problems; neurological and hematological symptoms; and adverse dermal effects (Davies, Freed, and Whittemore, 1982; Spear, 1991). Affected farmers could experience productivity losses due to

impaired work capacity in the field and reduced management and supervision abilities. To the extent that farmers do not protect themselves from the chronic health effects of pesticides, they will overvalue their benefits and hence use them beyond the private or social optimum amount. The possible effects of pesticide exposure on cancer and reproductive problems are not considered in this study, but could also lead farmers to overuse pesticides.

The empirical approach developed in this paper is based on a three-step procedure. The first step involves the construction of a variable measuring health impairment, based on data generated by clinical examinations of a subset of farmers in the production survey. This health impairment variable is defined as the opportunity cost of observed illnesses and is measured as the lost work time plus medical costs required to recuperate from observed symptoms. This health variable is then used as the dependent variable in a model that explains the observed variation in health across farmers as a function of personal characteristics of the farmers and their use of insecticides and herbicides. This model is used to generate estimates of health impairment associated with pesticide use for the larger sample of farmers in the production survey. The second step of the analysis is to include the estimated health impairment variable as an explanatory variable in a cost function to estimate jointly the productivity of pesticides and the productivity effects of health impairment. The third step is to use the results from the first two steps in a policy simulation in which the production and health relationships that were estimated econometrically are jointly simulated. This simulation model provides the basis for evaluating the productivity and health tradeoffs of policies that would restrict pesticide use.

The results of the study show that in two major rice-producing regions of the Philippines, pesticide use has a significant, negative effect on farmer health, and that farmer health has a significant positive effect on productivity. The simulation analysis shows that reducing the use of the most toxic materials, insecticides, would have a small effect on productivity because the productivity loss from reduced pest control would be offset by the productivity gain from improved farmer health. Therefore, policies that reduce insecticide use in Philippine rice production would be likely to generate an unambiguous improvement in social welfare through an improvement in farmer health, even if there are no other negative externalities associated with the use of these pesticides. The social benefits of restricting both insecticides and herbicides would be smaller and possibly negative, because the yield impact of reducing both herbicide and insecticide use would be greater and the health benefits only slightly greater than a restriction on insecticides alone. Therefore, it can be concluded that it would be more efficient to target pesticide restrictions at the most hazardous and least productive materials rather than restricting all pesticides regardless of their health or productivity attributes. Based on these findings, it is argued that if health

effects are not considered in the economic assessment of the modern rice technology, the ex ante rate of return to general rice research may be overestimated, while the rate of return to technology that reduces pesticide use may be underestimated, thus biasing the allocation of resources in rice research.

### **13.1. Measuring the Health Effects of Pesticide Exposure**

The health study was conducted on two groups of farmers in the Philippines where pesticides were known to have been used for more than two decades. A sample of thirty-one farmers and twenty-five pesticide applicators from the Laguna region of Southern Luzon and forty-two farmers and fifteen pesticide applicators from the Nueva Ecija region of Central Luzon were selected randomly for this study. These samples are subsets of a larger group of farmers in both locations that have been periodically monitored by the International Rice Research Institute over the past two decades. For the data used in this study, the sample households were monitored weekly and records were kept of all input and technology use practices with special emphasis on pest management practices, including safety practices used in handling pesticides. The Laguna sample was monitored for five crop seasons from 1987 to 1990, while the Nueva Ecija sample was monitored for four crop seasons from 1988 to 1991.

All fifty-six Laguna respondents and fifty-seven Nueva Ecija respondents were brought to the medical clinic at the International Rice Research Institute for a detailed health assessment, after the 1989 wet season crop and after the 1991 dry season crop, respectively. This included a detailed physical and laboratory examination of each individual plus a documentation of personal health history and habits.<sup>2</sup> Out of this sample, twenty-two observations from Laguna and forty-two observations from Nueva Ecija corresponded to farmers represented in the production data used in this study. Thus, the sample studied here represents only farmers who applied their own pesticides using backpack sprayers.

The results of the health assessment indicate that farmers and agricultural workers face chronic health effects due to prolonged exposure to pesticides. Eye, dermal, pulmonary, neurologic, and kidney problems were found to be significantly associated with long-term pesticide exposure (for details, see Chapter 12). The relationship between these symptoms and pesticide use are discussed below. One or more of these symptoms could lead to lower productivity due to the farmer's being absent from work during treatment and recuperation or to impaired capacity of the farmer to do a full load of work. The following pesticide-related health abnormalities were addressed.

### **13.1.1. *Eye Problems***

Pesticides such as 2,4-D and acetamides are known eye irritants (Morgan, 1977). Chronic irritation of the eye could lead to the formation of pterygium, a vascular membrane over the cornea, which can cause diminished vision. Twenty-five percent of the Laguna sample and 67 percent of the Nueva Ecija sample were diagnosed as showing symptoms of pterygium.

### **13.1.2. *Dermal Problems***

The skin is the main biode for entry of pesticides. Dermal contamination occurs during application as well as during mixing and handling of concentrated formulations (Coutts, 1980). The risk of dermal contamination is greater with the backpack sprayer typically used in the Philippines as compared to a spinning disc applicator or an electrodyne sprayer (Durand, Pascoe, and Bingham, 1984). Dermal absorption of the chemicals is enhanced by perspiration and the high temperatures typical of the tropical lowland conditions in the Philippines (Morgan, 1977). Eczema and nail destruction are common symptoms of chronic pesticide exposure (Morgan, 1977; WHO, 1982; Castañeda, Maramba, and Ordas, 1990). Fourteen percent of the Laguna sample and 46 percent of the Nueva Ecija sample were found to be suffering from chronic dermal disorders.

### **13.1.3. *Respiratory Problems***

The lung is an important biode of entry for airborne pollutants. There is an immediate intimate contact between the lung alveoli and the pesticide aerosol. The lungs are an important site for the binding or metabolism of organophosphate compounds (Nemery, 1987). Bronchial asthma is the most common chronic lung abnormality that could be attributable to long term pesticide exposure (Morgan, 1982; Hock, 1987; Nemery, 1987). Smoking can also cause respiratory abnormalities. Pingali, Marquez, Palis and Rola in Chapter 12 of this book, demonstrates control for the smoking effect in an analysis using a logit model. They find that the risk of respiratory abnormalities is significantly related to pesticide exposure even when the confounding effect of smoking is accounted for.

### **13.1.4. *Neurologic Problems***

Organophosphate compounds and 2,4-D are known neurotoxicants (Morgan, 1977). Both have been implicated as causative agents for polyneuropathy, a

syndrome characterized by paralysis or weakness of muscles of the arms and legs usually accompanied by a "glove and stocking" distribution of sensory loss and diminished deep tendon reflexes (WHO, 1990; Jaeger, 1976). Five percent of the Laguna sample and 11 percent of the Nueva Ecija sample were found to exhibit symptoms of polyneuropathy. Alcohol consumption is a confounding variable for the incidence of polyneuropathy, and when this is accounted for, 8 percent of the Nueva Ecija sample exhibit symptoms of polyneuropathy while none of the Laguna sample do. The prevalence of polyneuropathy in Nueva Ecija may be explained by the use of monocrotophos and 2,4-D.

### *13.1.5. Kidney Problems*

The kidneys help to ensure the efficient functioning of body cells through a number of mechanisms: regulation of extracellular fluid volume, control of electrolytes and acid-base balance; excretion of toxic and waste products, and conservation of essential substances (WHO, 1990). The kidney is highly exposed to circulating toxins and long-term exposure to organophosphate compounds could lead to renal tubular abnormalities (Davies, Freed, and Whittemore 1982). Nephrotoxic agents such as endrin and endosulfan are also known to cause kidney abnormalities (Morgan, 1977). Medical examinations of the sample farmers revealed that 43 percent of the Laguna farmers and 26 percent of the Nueva Ecija farmers suffer from kidney abnormalities. The greater use of endosulfan among the Laguna sample could explain the higher incidence of kidney problems in Laguna.

Although the above illnesses can be directly related to pesticides, pesticides also cause other nonspecific illnesses and lead to the lower health status of the farmer. In order to relate farmer health to pesticide exposure, a general indicator of health impairment was constructed that is comparable across illnesses. Medical examinations provided for each respondent an assessment of the ailments he or she experienced and the seriousness of these ailments. These assessments provided the basis for the estimation of the costs of treatment and recuperation. The level of health impairment of individual farmers was measured as the cost of the treatment recommended by the medical team, plus the opportunity cost of the farmer's time required to recuperate. (The opportunity cost of the farmer's time was proxied by the off-farm wage, because the Laguna and Nueva Ecija labor markets are closely linked to the Manila labor market, the main alternative to farm employment.) As noted by Cropper and Freeman (1991), a complete measure of the cost of health impairment would also include defensive or averting expenditures, the disutility associated with illness and the loss of leisure, and changes in life expectancy. The data collected from these farmers show that averting expenditures are minimal, and data are not available to value the disutility

of illness or to infer changes in life expectancy. Thus, the measure of health impairment used here is likely to be an underestimate of the total value of the diminution in the individual's well-being. However, this measure of health impairment should be positively related to the individual's ability to do farm work and thus should be correlated with farm productivity, as discussed below.

In order to identify the relationship between pesticide exposure and health impairment, a regression model was estimated to explain the health impairment variable as a function of farmer age; nutritional status, proxied by the weight/height ratio; dummy variables indicating whether the individual smokes tobacco or drinks alcohol; and the number of times he or she applied chemicals and the types of chemicals applied. Average farmer age for the two samples was similar, fifty-one years in Laguna and forty-nine years in Nueva Ecija. The data collected on self-protection measures showed little variation across farmers, so these factors could not be used as explanatory variables in the analysis.

The environmental economics literature contains examples of health production functions used to estimate, for example, the effects of urban air quality on respiratory illness (Portney and Mullahy, 1986; Ostro, 1983). Typically, these studies have examined responses of health to changes in ambient air quality using large surveys of a heterogeneous population. A large number of explanatory variables are included in these models to control for differences in the population. Atkinson and Crocker (1992) provide an analysis of the possible biases in these analyses caused by misspecification and errors in measurement. They emphasize the biases that may arise from the use of a large number of highly correlated explanatory variables measured with error.

The analysis presented here differs from those in the environmental economics literature in several important respects. The data analyzed here are drawn from a homogeneous population in terms of socioeconomic characteristics, nutrition, and environmental factors that may affect health, thus reducing the problems associated with population heterogeneity. Moreover, because the health data and the explanatory variables were collected by direct interviews, the data can be expected to be more accurate than those collected by other survey methods. However, the sample size available for this analysis is much smaller than those typically used in the environmental economics literature. Thus, the larger surveys may provide more precise estimates but may be subject to larger biases due to measurement error, whereas the smaller survey analyzed here may entail a lower degree of statistical precision but may be relatively free of the biases caused by measurement error. Until a detailed analysis of the differences in these types of data can be conducted, it will not be possible to know which one is likely to produce more reliable information.

Pesticide exposure was measured by the types of chemicals used and the number of times they were applied in the crop season preceding the medical examination. The World Health Organization (WHO) classifies agricultural



Table 13.1. Averages and Ranges of the Variables Used to Estimate the Health Impairment Equations

| <i>Variables</i>                                        | <i>Laguna (n = 22)</i> |             | <i>Nueva Ecija (n = 42)</i> |             | <i>Pooled (n = 64)</i> |             |
|---------------------------------------------------------|------------------------|-------------|-----------------------------|-------------|------------------------|-------------|
|                                                         | Average                | Range       | Average                     | Range       | Average                | Range       |
| Age                                                     | 51.32                  | 24–78       | 48.69                       | 22–70       | 50.4                   | 22–78       |
| Weight/height                                           | 23.34                  | 17.56–33.27 | 24.79                       | 18.22–34.96 | 24.36                  | 17.56–34.96 |
| Number of applications of category I and II chemicals   | 1.0                    | 0–3         | 1.0                         | 0–2         | 1.0                    | 0–3         |
| Number of applications of category III and IV chemicals | 1.0                    | 0–2         | 1.0                         | 0–2         | 1.0                    | 0–2         |
| log health impairment index                             | 8.26                   | 6.38–9.39   | 7.94                        | 0–9.52      | 8.05                   | 0–9.52      |

pesticides into four categories based on their relative acute hazard level. Category I chemicals are the most hazardous, while category IV chemicals are the least hazardous. While this classification is primarily for acute hazard, and no formal classification is available for chronic hazards, medical experts suggest that categories I and II are also most likely to be associated with chronic hazards. On this basis, the analysis presented here differentiates between two groups of pesticides, those in categories I and II, and those in categories III and IV. Most of the insecticides used in the Philippines fall in the more hazardous categories I and II, while the herbicides used are in the relatively less hazardous categories III and IV. The number of applications of category I and II chemicals ranged from zero to three in Laguna and zero to two in Nueva Ecija. The number of applications of category III and IV chemicals ranged from zero to two in both samples. The data used in the following analysis are summarized in Table 13.1.

A wide variety of pesticides are utilized by Philippine rich farmers, including insecticides, herbicides, and molluscicides. Insecticides used include the organochlorine endosulfan; organophosphates such as methyl parathion, monocrotophos, and chlorpyrifos; carbamates such as BPMC, carbaryl, and carbofuran; and pyrethroids such as cypermethrin and deltamethrin. All of the insecticides used are classified as category I or II according to the World Health Organization's hazard classification. The principal herbicide used was butachlor, although some 2,4-D was also used. These materials are classified as categories

IV and II under the WHO system. Thus, in the study conducted here all of the insecticides used were category I and II, and most of the herbicide used was category IV.

Pesticide exposure was proxied using both total pesticide applied during a season and the number of applications. The amount of active ingredient typically applied of these materials ranges from a few grams per hectare of some insecticides such as pyrethroids to many kilograms per hectare of other insecticides and herbicides. Therefore, the total amount of active ingredient applied, unweighted according to health risk, would not be expected to correlate well with the health status of farmers. This problem exists even when materials are classified by hazard category, because there is a wide variation in amounts of active ingredient applied within categories (e.g., both pyrethroids and 2,4-D are classified as category II, and whereas a few grams of pyrethroid are typically applied per hectare, 2 kilograms of 2,4-D are applied per hectare). However, under the assumption that farmers typically apply a standard dose of a given type of material, the number of applications by hazard category should be a reasonable proxy for exposure. Indeed, the number of applications was found to exhibit more explanatory power in the statistical analyses.

The results of the models using the logarithm of  $(1 + \text{number of applications})$  as explanatory variables are presented in Table 13.2. The samples for these models are the twenty-two farmers in Laguna and the forty-two farmers in Nueva Ecija who were represented in both the medical and economic data. The data show that age is positively related to health impairment, and that weight/height (a proxy for overall health and nutrition) is negatively related to health impairment, as expected. The smoking and drinking coefficients are statistically insignificant, and two of the four have negative signs, contrary to theoretical expectations. The table shows that in Laguna, in Nueva Ecija, and in the pooled sample, the numbers of category I and II pesticide applications are significantly and positively related to the level of health impairment, with an estimated elasticity of 0.32 to 0.37 in Laguna and 0.75 to 0.79 in Nueva Ecija. The number of category III and IV applications does not have a statistically significant effect in any of the models. The F-statistic for the test of a significant difference between the parameters for Laguna and Nueva Ecija is 0.65, indicating that the parameters for the two groups are not significantly different.

Thus, the data suggest that there is a statistically significant, stable relationship between numbers of applications of category I and II pesticides and human health impairment. In the subsequent section of the paper, the predicted value of this model is interpreted as a measure of the health impairment associated with pesticide use. For this purpose, observe that these equations can be interpreted much like hedonic regressions or instrumental variables regressions. That is, given an individual's personal characteristics, the predicted value of the model represents the component of health impairment associated with pesticide use.

Table 13.2. Estimated Health Impairment Model for Rice Farmers in Laguna and Nueva Ecija, Philippines

Dependent variable: log of Health Impairment Index

| <i>Independent Variables</i>                                        | <i>Laguna</i>                 |                                 | <i>Nueva Ecija</i>            |                                 | <i>Pooled</i>                  |
|---------------------------------------------------------------------|-------------------------------|---------------------------------|-------------------------------|---------------------------------|--------------------------------|
| Intercept                                                           | 9.78***<br>(1.02)             | 9.90***<br>(1.37)               | 6.08***<br>(1.70)             | 6.47***<br>(2.142)              | 7.26***<br>(1.21)              |
| Age                                                                 | 0.016*<br>(0.008)             | 0.018*<br>(0.009)               | 0.044*<br>(0.022)             | 0.033 <sup>ns</sup><br>(0.024)  | 0.033**<br>(0.013)             |
| Weight/height                                                       | -0.122***<br>(0.034)          | -0.128***<br>(0.040)            | -0.06 <sup>ns</sup><br>(0.05) | -0.048 <sup>ns</sup><br>(0.06)  | -0.073*<br>(0.038)             |
| Number of applications<br>of category I and II<br>chemicals (log)   | 0.371**<br>(0.180)            | 0.316*<br>(0.184)               | 0.75*<br>(0.45)               | 0.792*<br>(0.447)               | 0.541**<br>(0.276)             |
| Number of applications<br>of category III and IV<br>chemicals (log) | 0.061 <sup>ns</sup><br>(0.29) | 0.192 <sup>ns</sup><br>(0.356)  | 0.62 <sup>ns</sup><br>(0.91)  | 0.799 <sup>ns</sup><br>(0.94)   | 0.048 <sup>ns</sup><br>(0.486) |
| Smoke                                                               |                               | -0.196 <sup>ns</sup><br>(0.297) |                               | 0.525 <sup>ns</sup><br>(0.636)  |                                |
| Drink                                                               |                               | 0.024 <sup>ns</sup><br>(0.271)  |                               | -0.886 <sup>ns</sup><br>(0.697) |                                |
| R <sup>2</sup>                                                      | 0.54                          | 0.56                            | 0.25                          | 0.29                            | 0.24                           |
| Regression F-value                                                  | 5.94***                       | 3.89                            | 3.07**                        | 2.37                            | 4.71***                        |
| Number of Observations                                              | 22                            | 22                              | 42                            | 42                              | 64                             |

Note: Figures in parentheses are standard errors.

\* = significant at .10,

\*\* = significant at .05,

\*\*\* = significant at .01

ns = not significant.

### 13.2. Modeling Productivity Effects of Pesticide-Induced Illness

Health is an important component of human capital that affects the ability to do physical labor and to manage farm operations. As noted above, there is a substantial literature on which to build an analysis of the productivity effects of pesticide-induced illness. One strand of literature focuses on the productivity effects of education, wherein human capital is found to have effects on technical and allocative efficiency and on the quantity and quality of the farmer's physical labor. Another strand of literature addresses the effects of nutrition on health and productivity. The model presented here integrates aspects of both of these literatures.

Several assumptions are made to simplify the theoretical and empirical models. First, it is assumed that input choice is not a function of the adverse health effects of pesticide use. Family labor productivity and overall farm productivity are affected by the adverse health effects of pesticide exposure, but those productivity effects do not feed back and simultaneously affect the pesticide use decision. This assumption is justified by the evidence from the Philippines indicating that farmers are not generally aware of the chronic effects of pesticide exposure. This assumption simplifies the comparative static analysis of the model but is not required for the empirical analysis, as health is treated as an endogenous variable in the estimation procedure described below.

A second assumption is that the household production problem is separable into two stages. In the first stage, the farm family plans its allocation of time across household production, farm production, off-farm work, and leisure activities. In the second stage, other production inputs are allocated optimally given the family labor-time allocation. If pesticide use was perceived to impair health and thus affected the allocation of family labor time, it would not be reasonable to separate pesticide use decisions from the allocation of time. Household production decisions affecting labor allocation would then have to be integrated into the crop production analysis.

Studies conducted in the Philippines indicate that while farmers are aware of the acute health effects of pesticides, they are generally unable to associate pesticide use with the chronic health effects of long-term exposure to pesticides (Chapter 3; Rola and Pingali, 1993; Rola, 1989). Farmers are also not aware of the differences in hazard levels between category I and II pesticides and categories III and IV pesticides (Chapter 3). In general, farmers have not related their pesticide use, storage, and disposal practices to incidences of chronic pesticide-related illnesses. This difference is presumably because the cause-effect relationship is more apparent in the acute case. Thus, the aforementioned assumptions are reasonable for Philippine rice production.

A third assumption is that farm management decisions can be described as static profit maximization or cost minimization. More generally, of course, farmers may be risk averse, and the production process may be more accurately described as a sequential decision problem, particularly in the analysis of pesticide use. The use of sequential decision rules would cause pesticide applications and final output to be functions of random pest events, hence pesticide use would be endogenous to output, as shown by Antle (1988). Two considerations lead us to employ the simpler static model in this study. First, an empirically tractable production model is needed for use in policy simulations. Second, data on production practices of Philippine farmers indicate that a static, risk-neutral model may be a reasonable approximation to reality. IRRI entomologists and economists find that these farmers do not utilize integrated pest management

strategies or other sequential decision rules that would cause pesticide applications to be endogenous to output (Rola and Pingali, 1993; Teng, 1990; Herdt, Castillo, and Jayasuriya, 1984). Other evidence suggests that farmers do not understand the effects of pesticides on the higher moments of the yield distribution. Under these conditions, the risk-reducing effects of pesticides would be ignored and pesticide use decisions would be the same as those made by risk-neutral decision makers. Antle and Crissman (1990) find that farmers do not make risk-efficient decisions when using modern inputs. Rola and Pingali (1993) find that high levels of pesticide use are associated with imperfect information about pest incidence and pesticide effectiveness rather than with risk aversion. Farmers' perceptions of pest-related yield losses are anchored around levels observed during major infestations, even when the probability of such infestations is low. Both of these studies are thus consistent with the use of a risk-neutral model to represent these farmers' behavior.

Finally, the analysis is simplified by assuming that family and hired labor are perfect substitutes when employed doing field labor, and that labor markets are competitive so that returns to farm work and off-farm work are equilibrated. Family time is assumed to be allocated among household production, farm work time, off-farm work, and leisure to maximize the household's full income, composed of farm income, off-farm income, household production, and leisure. In equilibrium, an interior solution equates the marginal value of time across these activities.

The time devoted to farm production,  $T^p$ , is divided between management  $M$  and field work  $F$ . Following the approach originally suggested by Bliss and Stern (1978) and also adopted in Strauss's (1986) analysis of the effect of nutrition on farm productivity, let effective management input be

$$M^e(I, M) = m(I)M, \quad \partial m / \partial I < 0,$$

where  $I$  is the health impairment variable defined above. (Note that the farmer's education may also influence the effective management input. However, the data in this study do not provide sufficient variation in education levels to identify this effect, and it is therefore not included in the presentation of the model.) Similarly, effective family labor input is

$$F^e(I, F) = f(I)F, \quad f' < 0.$$

Total effective field labor is  $L^e = F^e + H^e$ , where  $H^e$  is hired labor. Note that the productivity of hired labor also could be reduced by pesticide exposure, but under the assumption that farmers remunerate labor in effective units, this would affect hired labor income and well-being but not farm productivity.

Crop yield is  $Y(X, L^e, M^e, Z)$ , where  $Y$  is yield,  $X$  represents variable inputs, including insecticides and herbicides (generally a vector), and  $Z$  represents fixed

factors. This function is assumed to exhibit standard curvature properties with respect to all inputs. Letting  $P$ ,  $w_s$ , and  $w_H$  be prices, the farmer is assumed to choose  $X$ ,  $H^e$ ,  $F$ , and  $M$  to maximize net returns,

$$\pi^p = PY(X, L^e, M^e, Z) - w_s X - w_H H \quad (1)$$

subject to

$$T^p = F + M, \quad L^e = F^e + H^e, \quad M^e = m(I)M, \quad F^e = f(I)F.$$

Solving the input and output choice problem gives factor demand functions for  $X$ ,  $M$ ,  $F$ , and  $H^e$ , and the output supply function. In this model the marginal value of family labor is equal to the hired wage rate  $w_H$ . In a competitive labor market equilibrium, the hired wage is also equal to the net off-farm wage and thus the marginal value of family labor is equalized across all farm and nonfarm production and leisure activities.

The comparative static properties of this model with respect to prices can be shown to be similar to the conventional profit maximization model. The comparative static properties with respect to health impairment,  $I$ , deserve special comment, however. When  $I$  increases exogenously, overall productivity should decrease, thus  $\partial Y / \partial I < 0$ , due to reduced effective management input and effective family field labor input. But the comparative static effects of  $I$  on actual family labor inputs  $M$  and  $F$ , and on effective hired labor and other inputs, are generally ambiguous. This ambiguity arises because the effect of lower overall productivity may be partially offset by the substitution of hired labor or other inputs for family labor input. The effect on the allocation of family labor to management and field labor can be shown to depend on the relative marginal productivities of management and field labor and the relative impacts of illness on the ability to perform field labor and management tasks.

The factor demand functions and the output supply functions can be used to derive the restricted cost function  $C(Y, w, Z, I)$  and the restricted profit function  $p(P, w, Z, I)$ . According to the approach developed by Welch (1970) and by Schultz (1975), farm management ability should be reflected in both the technical efficiency of the production process and the allocative efficiency of input and output decisions. Applying the Envelope Theorem to the cost minimization implied by the above profit-maximization problem, it can be shown that the derivative  $\partial C / \partial I$  is positive. This derivative measures the effect of illness on technical efficiency and on the efficiency of input allocation decisions. A similar analysis shows that  $\partial p / \partial I < 0$ . This latter term captures the efficiency effects embodied in the cost function plus the effects of health on the efficiency of output decisions. Because the output decision is made at the beginning of the growing season, the principal effects of illness caused by pesticide use during

Table 13.3. Averages and Ranges of the Variables in the Estimated Cost Functions for Laguna and Nueva Ecija Rice Production

| <i>Variables (log)</i>  | <i>Laguna (n = 126)</i> |            | <i>Nueva Ecija (n = 64)</i> |            |
|-------------------------|-------------------------|------------|-----------------------------|------------|
|                         | Average                 | Range      | Average                     | Range      |
| Yield                   | 8.26                    | 7.23–9.12  | 8.58                        | 8.26–9.18  |
| Wage                    | 3.67                    | 2.72–4.43  | 3.81                        | 3.21–4.007 |
| Fertilizer price        | 2.05                    | 1.73–2.34  | 2.37                        | 1.52–2.86  |
| Insecticide price       | 0.92                    | –2.12–3.82 | 1.20                        | –0.43–3.56 |
| Herbicide price         | 0.53                    | –1.2–1.06  | 1.54                        | –0.18–2.29 |
| Health impairment index | 8.25                    | 7.58–9.17  | 7.62                        | 6.83–8.3   |

the seasons should be captured by the cost function. Therefore, a restricted cost function is utilized in this study to measure the productivity effects of health.

### 13.3. Estimates of the Productivity Effects of Health

The productivity effects of health were estimated for the two regions in the Philippines corresponding to the health model discussed above, the Laguna region in Southern Luzon and the Nueva Ecija region in Central Luzon. These regions are both characterized by low-land irrigated rice production where two to three crops of rice are cultivated per year using modern rice technology. The productivity gains made by these regions through the adoption of modern rice technology are documented in Herdt (1987).

The Laguna sample consisting of thirty-one farm households was monitored over five crop seasons between 1987 and 1989. The Nueva Ecija sample consisting of forty-two households was monitored for one crop season in 1991. Production data for 1988 was available for twenty-eight of these households. Panel data were constructed for both the Laguna and Nueva Ecija samples for estimating the rice cost function. A total of 126 observations with complete data were available from Laguna and sixty-four from Nueva Ecija. Summary statistics for both samples are provided in Table 13.3.

A fundamental problem in the estimation of pesticide productivity is the aggregation of many different types of materials into a category such as insecticides. In this study, a wide array of different insecticides were found to be used by Philippine rice farmers, including organophosphate materials applied at several kilograms per hectare and pyrethroids applied at several grams per hectare. Clearly, it would be inappropriate to simply add together the active ingredients of materials that are applied at such different rates. Therefore, a hedonic price regression procedure was employed to quality adjust the insecticides and

herbicides into standardized units, along the lines of the procedure used by Antle (1988). In this procedure, prices per unit of active ingredient are interpreted to be functions of a quality component reflected in application rates, and other factors such as weather, safety, or other supply or demand factors that are uncorrelated with pesticide efficacy. Thus, prices were regressed on polynomial functions of observed application rates, and on dummy variables for seasons and generic pesticide categories. Setting the dummy variables to zero, the predicted values of the model were interpreted as quality factors and used to aggregate the quantities into standardized units. One hedonic model was estimated for insecticides and one for herbicides.

The theoretical model described in the previous section can be transformed into an econometric model by specifying a functional form for the cost function. In this paper, a Cobb-Douglas cost function is used. There are several justifications for the use of the Cobb-Douglas model. The model is parsimonious in the parameters, can be interpreted as a first-order approximation to the true cost function, and is globally well behaved. This latter property is particularly important for the use of the model in the policy simulations presented below. Estimates of more flexible translog functions showed that the Cobb-Douglas specification is also a good approximation, as most parameters of second-order terms were not statistically significant. The literature on flexible functional forms shows that second-order approximations such as the translog function may provide more accurate estimates of substitution elasticities. However, a second-order approximation such as the translog does not satisfy the concavity properties of the cost function globally, and its use would therefore greatly complicate the simulation analysis discussed in the following section.

An additional comment about the specification of the cost function is in order, concerning the criticisms of the Cobb-Douglas production specification for estimation of the marginal productivity of pesticides in the literature (Lichtenberg and Zilberman, 1986). If the production function were specified as log-linear in the labor input  $L$ , it would not be log-linear in effective hired labor  $H^e$  and family field labor  $F$  because of the assumption of perfect substitution between these two. Thus, the cost function  $C(Y, w, Z, I)$  that is dual to a log-linear production function  $Y(X, L^e, M^e, Z)$  would not be in the Cobb-Douglas form. More generally, whatever form of production function is assumed as a function of  $L$  will not take the usual form of that function's dual. Consequently, the Cobb-Douglas cost function can be interpreted as a first-order logarithmic approximation to the true cost function, but not as the function that is dual to the Cobb-Douglas production function.

For estimation of the Cobb-Douglas cost function model, variable cost was defined as the cost of fertilizer, hired and family field labor for preharvest operations, insecticides, and herbicides. Cost and output were measured on a



per-hectare basis. Because seed and other inputs (e.g., bullock and mechanical labor) for field preparation and planting are utilized in essentially fixed proportions with land, they were not included in the model in order to avoid multicollinearity problems. Preliminary estimates of the model indicated that adverse weather in several seasons in the sample resulted in output elasticities that implied increasing returns to variable factors. Seasonal dummy variables were introduced to interact with output to account for the impacts that seasonal weather variation has on returns to scale.

The health equation based on the pooled Laguna and Nueva Ecija data (Table 13.2) was used to generate the health impairment index variable used as an explanatory variable in the cost function. This predicted health impairment index is a function of insecticide and herbicide use and therefore may be endogenous to cost. In addition, output is endogenous to input decisions and thus to cost in a production model, as noted by Antle and Crissman (1988). Therefore, the instrumental variables method was used to estimate the cost function with output and the health variable treated as endogenous variables. Instruments used were output price, area planted, input prices, farmer years of schooling, annual dummy variables, and costs of animal labor, tractor power, fuel oil, and crop threshing. A system of five equations was estimated, the cost function in log-linear form and the four cost-share equations for labor, fertilizer, insecticides, and herbicides, with across-equation restrictions imposed. Linear homogeneity in prices was imposed on the cost function.

The estimated cost function coefficients for factor prices, output, and the health impairment variable are presented in Table 13.4. The coefficients are all estimated with a high degree of precision and the signs of the price coefficients are positive as predicted by economic theory. Using Shephard's lemma, the output-constant factor demand elasticities for the Cobb-Douglas cost function are equal to the factor price coefficients minus one. Thus, the results imply that the Hicksian factor demand elasticities for insecticides and herbicides are between  $-0.9$  and  $-1.0$ . The coefficient on yield indicates that cost per hectare is approximately proportional to yield, as would be the case when the technology exhibits constant returns to variable factors.

The point estimates of the health impairment parameters for the two regions both support the hypothesis that health impairment does have a statistically significant, negative impact on farm-level productivity, although the magnitude of this effect is larger in Nueva Ecija than in Laguna. This latter finding is consistent with the health equation estimates in Table 13.2 that show that the category I and II pesticides have a larger impact on health in the Nueva Ecija sample. Chapter 12 provides a historical comparison of the two sample regions and shows that the Nueva Ecija farmers use a greater proportion of the more hazardous category I and II chemicals and that their dosages are higher than

Table 13.4. Parameter Estimates of Cobb-Douglas Cost Functions for Rice Production, Laguna and Nueva Ecija, Philippines

|                        | <i>Laguna</i>      | <i>Nueva Ecija</i> |
|------------------------|--------------------|--------------------|
| Intercept              | -3.734<br>(-2.392) | -4.707<br>(-2.214) |
| Wage                   | 0.697<br>(78.655)  | 0.773<br>(47.474)  |
| Nitrogen price         | 0.200<br>(25.122)  | 0.164<br>(12.652)  |
| Insecticide price      | 0.067<br>(14.446)  | 0.031<br>(4.452)   |
| Herbicide price        | 0.036<br>(14.479)  | 0.033<br>(7.493)   |
| Yield                  | 0.967<br>(5.334)   | 0.900<br>(4.033)   |
| Health impairment      | 0.138<br>(3.133)   | 0.363<br>(3.427)   |
| Number of observations | 126                | 64                 |

Note: t-statistics in parentheses. Based on estimation of the cost function and share equations with across-equations restrictions and linear homogeneity imposed.

those of the Laguna farmers. For instance, in the 1989 dry season 52 percent of the Nueva Ecija sample used monocrotophos, a category I organophosphate, while only 33 percent of the Laguna sample used it. As discussed earlier, the incidence of respiratory illnesses and polyneuropathy increases with exposure to organophosphate compounds.

### 13.4. Simulation Analysis of the Impacts of Restricting Pesticide Use on Health and Productivity

The previous sections of this paper showed that there is a statistically significant effect of pesticide use on farmer health, as measured by the health impairment variable described above. It was also shown that health impairment is a statistically significant variable explaining production cost, thus implying that farmer illness has a negative impact on productivity. In this section, these two relationships are combined in a simulation analysis to investigate the impacts on health and productivity of restricting pesticide use.

In the simulation model, pesticide use is restricted by imposing a tax on pesticides. A pesticide tax should reduce pesticide use and thus improve farmers'

health but may also reduce productivity. However, the tradeoffs between health and productivity are not obvious because a reduction in pesticide use also has a positive impact on productivity through improved health. The simulation analysis is designed to explore these tradeoffs. Note that the use of a tax in the simulation analysis is not meant to imply that a tax is the policy instrument that would actually be used if a policy restricting pesticides were to be implemented. An equivalent quantitative restriction on pesticide use can be defined for each tax rate. These simulations are best interpreted as representing the typical farmer. In practice there may be differences for some farmers between a tax, which allowed pesticides to be used when needed although at a higher price, and a quantitative restriction that would limit availability of certain materials under regardless of an individual farmer's pest situation.

The following assumptions were made in the simulations. First, other variable inputs, fertilizer and labor, are held constant at sample mean levels. This assumption is made because it is believed that the most important category of pesticide in this case study, insecticides, is not highly substitutable with labor or fertilizers. Second, in order to make the results of the simulations conservative, the parameters of the health model and the cost function for Laguna are used. These equations show the smallest impacts of pesticides on health and the largest responsiveness of cost to pesticide prices, therefore, they will show a smaller impact of a pesticide tax on health and a larger impact on productivity than the model estimated for Nueva Ecija.

The simulation model is composed of the health equation from Table 13.2, the cost function, the demand functions for insecticides and herbicides derived from the cost function, and the marginal cost function. The system of equations used in the simulation are, in general form

$$\begin{aligned} I &= I(s, N^h) \\ C &= C(Y, w^s, w^h, I) \\ Q^i &= \partial C / \partial w^i \\ N^i &= Q^i / A^i, i = s, h \\ P &= \partial C / \partial Y, \end{aligned}$$

where  $I$  = health impairment variable,  $N^i$  = number of applications ( $i = s, h$ ;  $s$  = insecticides and  $h$  = herbicides),  $C$  = cost of production,  $Q$  = quantity of insecticide or herbicide,  $A^i$  = average application rate of quality-adjusted insecticide or herbicide,  $w^i$  = quality-adjusted insecticide or herbicide price,  $Y$  = yield, and  $P$  = output price.

Note that the health model is specified with numbers of applications of pesticides ( $N^i$ ) as explanatory variables, and the factor demand functions derived from the cost function represent quantities of pesticides. The average application rate ( $A^i$ ) is used to relate the two by specifying that  $N^i = Q^i / A^i$ .

Pesticide use could be restricted by taxing both insecticides and herbicides or

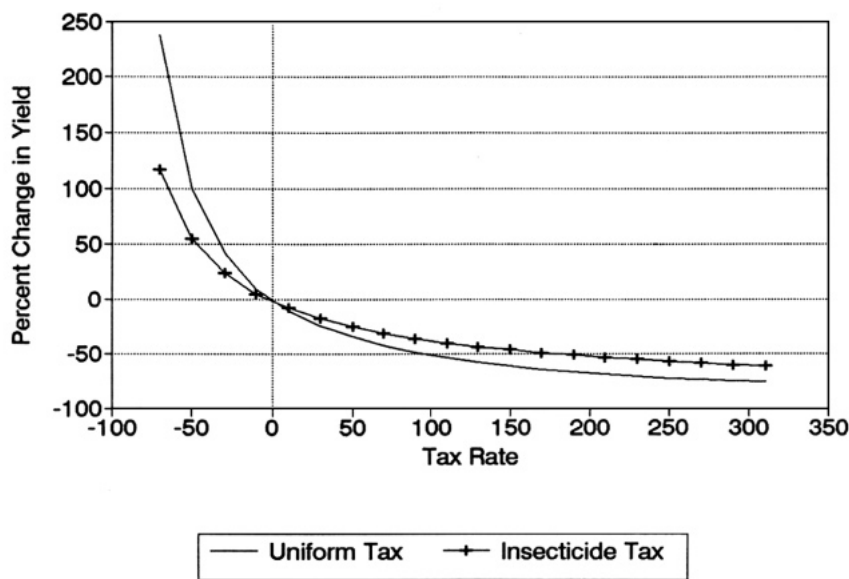


Figure 13.1. Simulated Impacts of Pesticide Tax on Rice Yields/Zero Health Effect

by taxing them differentially. As noted above, the insecticides are the most toxic substances (category I and II according to the World Health Organization system of classification), whereas the herbicides used are relatively less toxic (category IV). An efficient tax scheme designed to mitigate health impacts at least cost might not involve an equal tax on all pesticides. Therefore, both a uniform tax (equal tax rates) and a tax on insecticides only were investigated, using the following scenarios:

- A uniform tax on insecticides and herbicides, holding health constant. This scenario represents a base case in which it is assumed that health is not affected by pesticide use.
- A tax on insecticides only, holding health constant. This scenario provides an indication of the efficiency effects of taxing only the most hazardous materials, assuming there is no health effect of pesticides.
- A uniform tax on insecticides and herbicides, with health endogenous.
- A tax on insecticides only, with health endogenous.

The results of the policy simulations are presented in Figures 13.1 through 13.5. Each figure compares the effects of the uniform tax on both insecticides and herbicides to the effect of a tax on insecticides only.

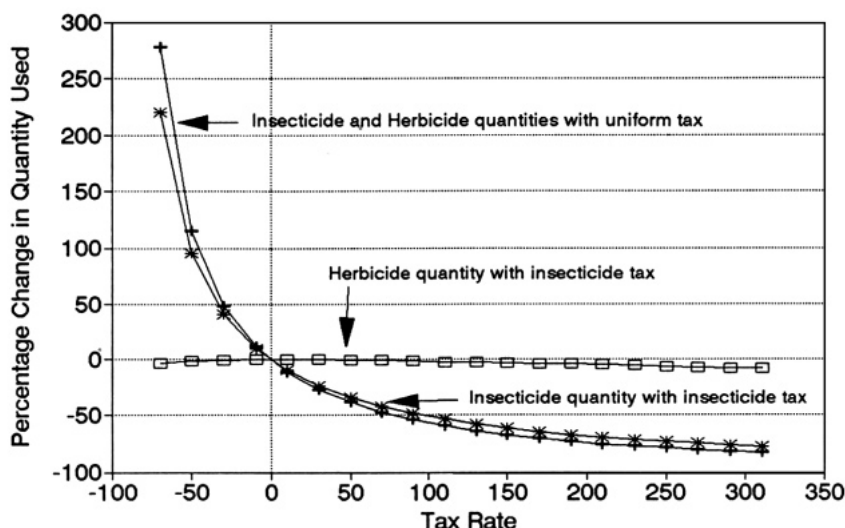


Figure 13.2. Simulated Impacts of Pesticide Tax on Insecticide and Herbicide Use

Figure 13.1 compares the yield effects of pesticide taxes under the assumption that there is no effect of pesticide use on health. As expected, the figure shows that the insecticide tax has a smaller effect on yield than the uniform tax.

Figures 13.2 to 13.5 show the results of the simulations of the model with health endogenous. Figure 13.2 shows the impacts of the pesticide taxes on pesticide use for both tax scenarios. The uniform tax reduces the use of both insecticides and herbicides by almost the same percentage amounts, with a 300 percent tax resulting in an 80 percent reduction in quantities used (the data points for insecticide and herbicide quantities under the uniform tax are indistinguishable in the figure). The insecticide tax reduces insecticide use somewhat less than the uniform tax, but it has almost no effect on herbicide use.

Figure 13.3 shows the impact of the pesticide taxes on health. As Figure 13.2 showed, the uniform tax reduces both insecticide and herbicide use and therefore has a greater impact on health than the insecticide tax alone. However, because the insecticides are much more toxic to humans than the herbicides, the insecticide tax is about 80 percent as effective as the uniform tax in reducing the health effects of pesticide use.

Figure 13.4 shows the yield effects of the taxes when health is assumed to be a function of pesticide use. Here two factors are at work reduced pesticide use causes lower yields, as was seen in Figure 13.1, but also improves health,

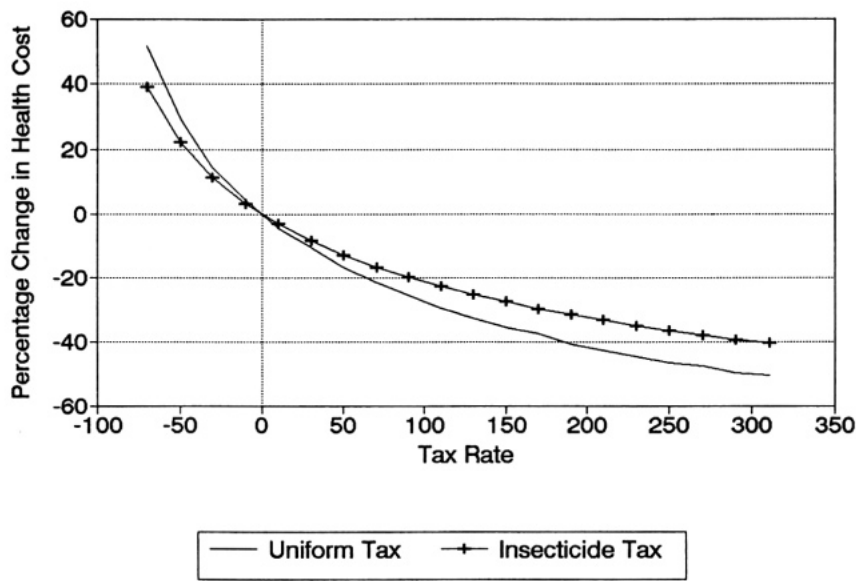


Figure 13.3. Simulated Impacts of Pesticide Tax on Pesticide-Induced Illness

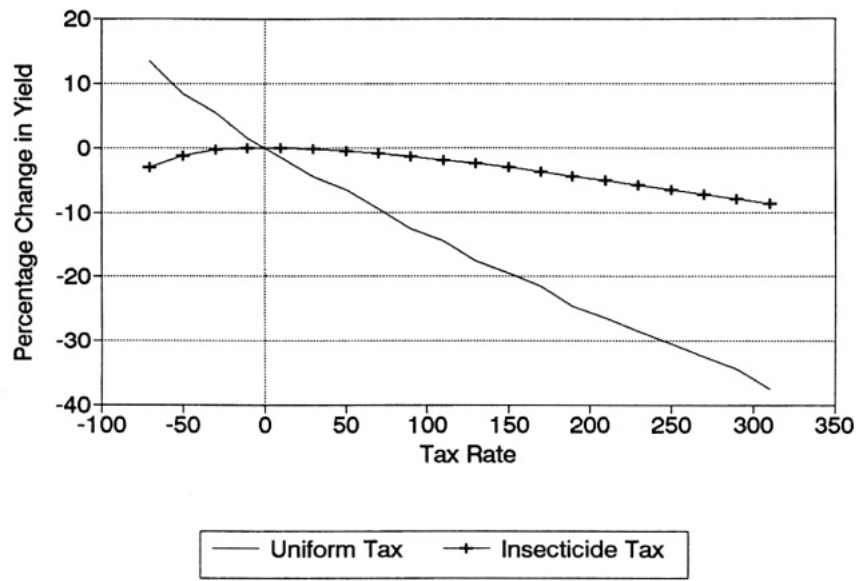


Figure 13.4. Simulated Impacts of Pesticide Tax on Yield/Endogenous Health

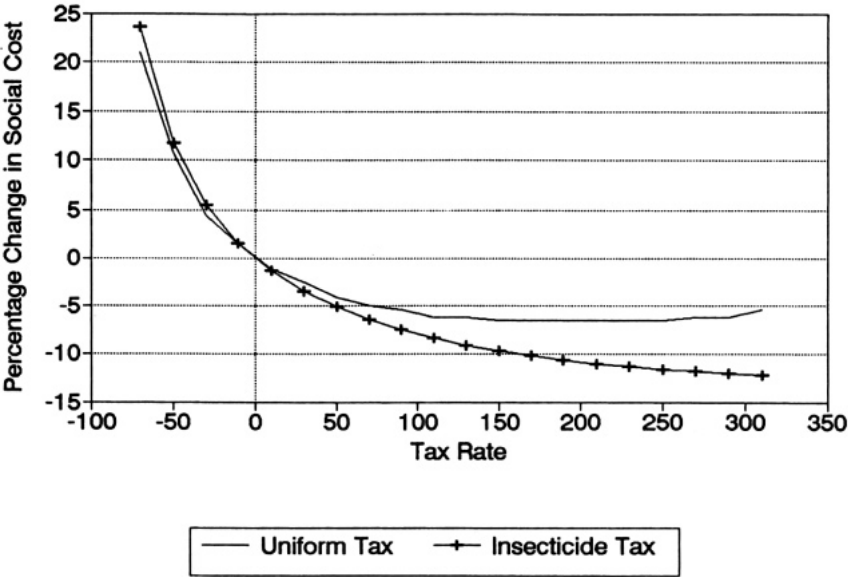


Figure 13.5. Simulated Impacts of Pesticide Tax on Average Social Production cost

as shown in Figure 13.3, so the net effect on yield is less than when health is assumed to be exogenous. However, because the uniform tax reduces productivity more and improves health more than the insecticide tax, it is unclear which tax would have more impact on productivity. The results of the simulation show that the insecticide tax alone has a much smaller effect on productivity because it reduces insecticide use almost as much as the uniform tax and is therefore almost as effective as the uniform tax in reducing the adverse health effects of pesticide exposure, but accomplishes these health gains without substantially reducing herbicide use.

The economic advantage of the insecticide tax over the uniform tax is also demonstrated in Figure 13.5, which shows the effects of the two tax scenarios on the average cost of production plus the estimated health impairment per unit of output. Recall that the health impairment variable was derived by estimating the treatment cost and foregone labor cost required to treat observed symptoms (but recall that the health impairment variable is likely to be an underestimate of the total cost of illness, as foregone leisure and reduced life expectancy are not accounted for). The figure shows that the average production plus health cost is monotonically declining over the range of the simulation for the insecticide tax. In contrast, the average production plus health cost achieves a minimum at

a 150 percent rate for the uniform tax and then increases slightly. This difference between the two scenarios is explained by the fact that the uniform tax has a larger opportunity cost in terms of foregone yield with only slightly greater health benefits. Thus, beyond a point, the yield losses outweigh the health benefits of the uniform tax.

These simulation results, it should be emphasized, were obtained using the cost function parameters for Laguna, which showed a smaller effect of health on productivity than the estimates for Nueva Ecija. Therefore, the same qualitative findings hold for Nueva Ecija, except that the social benefits of restricting insecticide use are commensurately greater.

### **13.5. Policy and Research Implications**

The findings of the econometric models and the policy simulations lead to a number of implications, ranging from those specific to the Philippine case study, to the broader questions of pesticide policy in developing countries and the research strategies of the national and international research organizations.

The findings of this study establish, for the case of irrigated rice production in two major regions of the Philippines, a consistent pattern showing that pesticide use has an adverse impact on farmer health, and that impairment of farmer health reduces productivity. The similarity between rice production conditions in the Philippines and other parts of Southeast Asia suggest that these relationships are likely to exist in other countries where pesticide use is also prevalent in rice production.

The findings of the simulation analyses show that there are likely to be social gains from a reduction in insecticide use in Philippine rice production. Reducing insecticide use is estimated to have a small net effect on productivity because the productivity loss from reduced pest control would be largely offset by the productivity gain from improved farmer health. Because the productivity effects are small, there should be little adverse impact of reducing insecticide use on total production or on consumers through higher rice prices. Therefore, policies that reduce insecticide use in Philippine rice production would be likely to generate an improvement in social welfare through an improvement in farmer health. The actual health benefits are likely to be greater than those estimated in this study for several reasons. The measure of health impairment may not account for the full social cost of illness, as it does not include the value of foregone leisure or reduced life expectancy and may understate the true opportunity cost of treatment and recuperation. Additional impacts on family members not directly involved in production, through incidental exposure and accidental poisonings, also have not been measured. Moreover, off-farm impacts



of agricultural pesticides, such as food or water contamination, have not been measured. Taking these additional possible effects into account would only strengthen these conclusions.

The uniform tax scenario implies that the social benefits of restricting both insecticides and herbicides would be smaller than the benefits of an insecticide tax only and could possibly be negative. This implication follows because the yield impact of reducing both herbicide and insecticide use was found to be greater and the health benefits only slightly greater than a restriction on insecticides alone. Thus, it can be concluded that there could be substantial social benefits from tailoring pesticide policies in relation to the degree of toxicity of the pesticide and its productivity.

These findings also have implications for the rates of return to agricultural research and for the allocation of research funds in programs at national and international research centers. The finding of a significant adverse health impact from pesticide use implies that *ex ante* estimates of the rate of return to general rice research based on experimental predictions of yield gains (see Barker and Herdt, 1985, and Rose, 1985, for a review of such studies) are likely to be overstated. These findings also suggest that the estimated rates of return on technologies that reduce pesticide use, such as varietal resistance to pests and integrated pest management methods, are generally understated because they do not include the health and productivity benefits associated with reductions in pesticide use.

Many countries have pesticide labeling laws and other regulations designed to protect farm worker safety, while other countries have no such laws. Yet even in countries like the Philippines where such laws do exist they often are not enforced. Protective clothing is rarely used by farmers, and few farmers obtain training in the safe handling and storage of pesticides. It could be argued that better farmer education and training in pesticide use and safety procedures would solve the problems identified in this study. However, pesticides have been used for more than two decades in the Philippines and other countries, and these health problems persist. Until the needed investments in the human capital of farmers are made, there appear to be two viable policy options to reduce the adverse health effects of pesticides: one is to restrict pesticide use through regulation of the price or availability of pesticides; the other is to find alternative methods of pest control that, like the modern seed varieties, do not require large investments in farmers' human capital for safe and effective use. In the long run, the best solution is likely to be to develop effective nonchemical control methods, such as varietal resistance to pests that can be embodied in seeds, or the use of natural enemies to pests and other biological controls. But in the short term, the only viable policy appears to be restricting pesticide use through restrictions on imports, production, and distribution of hazardous materials or through taxes on

pesticides. The problem with pesticide restrictions is that while health will improve, productivity may be reduced. The findings of this study provide evidence that the health benefits of pesticide regulations may be obtainable at a low cost in terms of foregone production through policies that target the most hazardous, least productive pesticides.

## Notes

1. An earlier version of this paper had been published in the *American Journal of Agricultural Economics* 76 (August 1994): 418–430.

2. The medical assessment was carried out by a medical team consisting of a physician, nurse, X-ray technician and medical technologists. The nurse interviewed the farmers regarding their personal, family, and occupational histories, including their drinking and smoking habits. The doctor performed a complete physical examination on all the farmers using a protocol especially designed for the project. Cholinesterase determinations were done by the medical technologist, while chest X-ray and electrocardiogram (EKG) were done by the X-ray technician. The readings for the EKG and the X-ray were done by two cardiologists and a radiologist, respectively.

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IV



# 14 PUBLIC REGULATORY ROLES IN DEVELOPING MARKETS: THE CASE OF PESTICIDES

P.L. Pingali and A.C. Rola

## 14.1. Introduction

The public regulation of input or product markets is warranted when one or more of the following market imperfections exist: (1) use of the product creates negative externalities, (2) end users face serious occupational hazards, (3) product quality is variable since standards are hard to enforce, (4) information about product efficacy is less than perfect, and (5) questions about ethics in marketing and trade arise since producers-exporters are more knowledgeable on each of the above issues than the importers-end-users.

The pesticide industry qualifies for public regulation by each of the above criteria. The human health and environmental consequences of indiscriminate and injudicious pesticide use are well documented both for the developed and developing countries. The public policy question with respect to pesticides in the developing world is not “Are regulations appropriate?” but rather “What types of regulations are appropriate?”

Discussions on pesticide regulation in developing countries center around three broad sets of questions: (1) should poor countries divert resources towards environmental protection; (2) do countries face a tradeoff between productivity



growth and environmental protection; (3) are developed country regulatory policies appropriate for and transferable to developing countries?

This paper reviews the current scenario, in developing countries, with respect to pesticide use, trade, and regulation, and assesses potential regulatory options for reducing the social costs of pesticide use. Regulatory policies are discussed relative to the above three questions and viable regulatory options are determined.

## **14.2. Current Scenario for Pesticides: Markets, Use, Effects, and Regulations**

### *14.2.1. Structure of the International Pesticide Market*

The international pesticides industry is characterized by vertical integration, a high degree of export orientation, product diversity, and a variety of important connections with national economies. It is also a capital intensive and research-intensive industry, involving dominant market positions by relatively few large companies and by a leading role on the part of relatively few countries (Boardman, 1986). World market growth has remained steady in the 1970s and 1980s at around 5 percent a year. Before 1960s, pesticides were mostly consumed in industrialized nations. With agricultural modernization in developing countries in the mid-1960s, third world exports became an important part of the international pesticide industry. Traditional exporters of agrochemicals are Britain (where chemicals constitute its third-largest export), the United States, West Germany, France, Switzerland, Italy, and Japan. In the 1960s and 1970s, these countries accounted for around 75 percent of world chemicals production (Boardman, 1986). Approximately 85 percent of all agrochemicals used in Asia are imported from the above countries (UN, 1990).

A large proportion of the pesticides exported to the developing countries are products that are not used in the developed world on environmental and health grounds. Weir and Shapiro (1981), for instance, pointed out that at least 25 percent of U.S. pesticide exports are products that are banned, are heavily restricted, or have never been registered for use in the United States. However, U.S. law (the Federal Insecticide, Fungicide, and Rodenticide Act) explicitly states that banned or unregistered pesticides are legal for export. Table 14.1 provides an example of the registration status in the United States of chemicals popularly used in the Philippines. Importing countries routinely recommend the use of these products, either due to ignorance or due to their being cheaper than the less toxic products.

Table 14.1. Registration Status in the United States of Pesticides Commonly Used by Filipino Farmers

| <i>Pesticide</i>     | <i>Registration Status<br/>in the United States</i> |
|----------------------|-----------------------------------------------------|
| <i>Insecticides:</i> |                                                     |
| Organochlorine:      |                                                     |
| Endrin               | No longer registered                                |
| Endosulfan           | Registered for general use                          |
| Organophosphates:    |                                                     |
| Methyl parathion     | For restricted use                                  |
| Monocrotophos        | No longer registered                                |
| Azinphos ethyl       | Not registered                                      |
| Diazinon             | For general use                                     |
| Malathion            | For general use                                     |
| Carbamates:          |                                                     |
| Isoprocarb           | Not registered                                      |
| Carbofuran           | For restricted use                                  |
| Methomyl             | For restricted use                                  |
| Carbaryl             | For general use                                     |
| BPMC + chlorpyrifos  | Not registered                                      |
| Pyrethroids:         |                                                     |
| Cypermethrin         | For restricted use                                  |
| Deltamethrin         | Not registered                                      |
| <i>Herbicides:</i>   |                                                     |
| Phenoxy:             |                                                     |
| 2,4-D                | Registered for general use                          |
| Acetamide:           |                                                     |
| Butachlor            | Not registered                                      |

Source: US. Environmental Protection Agency (1992).

#### 14.2.2. *Agricultural Modernization and the Demand for Agrochemicals*

In the developing world, agricultural modernization, which is meant to include agricultural intensification and increased market orientation, has led to a rapid growth in the demand for agrochemicals. The rapid spread of the Green Revolution for cereal crops, in Asia during the late 1960s and the 1970s, led to an upward shift in the demand for modern agricultural inputs, including pesticides. Although pesticides as a whole experienced a rapid growth in demand, an

Table 14.2. Intensification, Market Orientation, and Demand for Agrochemicals

| Land/<br>Labor<br>Ratio | <i>Market Orientation</i> |                              |                               |
|-------------------------|---------------------------|------------------------------|-------------------------------|
|                         | <i>Low</i>                |                              | <i>High</i>                   |
|                         | High                      | Low demand for all chemicals | Herbicides predominate        |
|                         | Low                       | Insecticides predominate     | High demand for all chemicals |

examination of the trends for chemical subgroups, such as insecticides, herbicides, and fungicides, indicates that there was substantial variation by country or region and by crop. The following is a stylized representation of the factors leading to these differences.

Table 14.2 shows the differential effects of increasing land scarcity and increasing market orientation on the demand for chemicals. Consider first a sparsely populated subsistence society with limited access to markets. Agriculture in such societies is characterized by extensive land use and an almost complete reliance on nontraded inputs, such as farmyard manure. Pest pressure is low in such cultivation systems and is kept that way through a variety of management practices, such as crop rotations and the use of traditional cultivars with known resistance to chronic pest problems.

Increasing land scarcity due to population growth in subsistence societies leads to agricultural intensification—that is, increased intensity of land use (Boserup, 1965; Pingali and Binswanger, 1987). Where the opportunity costs of family labor are low, food production continues to rely predominantly on nontraded inputs. Pest pressure increases with intensification due to increased carryover of pests spatially and temporally. While increased weed pressure is handled by family labor, increased insect pressure is no longer amenable to traditional management practices, and small amounts of insecticides begin to be used for cereal crops, even in subsistence societies. Low to moderate amounts of fungicides also tend to be used for crops such as cotton, tobacco, and horticultural products, especially fruit and vegetables (Table 14.3).

The contrasting scenario is one of a sparsely populated area that has excellent market access. In this case, agricultural intensification will be high due to high land values, but unlike the subsistence case, the opportunity cost of labor will also be high, hence the high levels of traded input use. While increasing insect pressures can be controlled through appropriate crop rotations and seasonal fallows, the dominant constraint is weeds. High levels of herbicide use are the norm in such societies. High fungicide use can also be observed for horticulture crops, especially fruit and vegetables (Table 14.3). Where market access and land scarcity are both high, high opportunity costs of land and labor result in

Table 14.3. Agrochemical Use by Stage of Agriculture and Cropping

| <i>Farm<br/>Characteristics</i> | <i>Cropping System</i>      |                                                      |                                                        |
|---------------------------------|-----------------------------|------------------------------------------------------|--------------------------------------------------------|
|                                 | <i>Cereals (e.g., Rice)</i> | <i>Other Field Crops<br/>(e.g., Cotton, Tobacco)</i> | <i>Horticulture<br/>(e.g., Fruits,<br/>Vegetables)</i> |
| Land abundant                   | All chemicals               | All chemicals                                        | All chemicals                                          |
| Subsistence                     | None                        | None–Low                                             | None–Low                                               |
| Land scarce                     | Insecticides                | Insecticides, Fungicides                             | Fungicides                                             |
| Subsistence                     | Low–Moderate                | Low–Moderate                                         | Low–Moderate                                           |
| Land abundant                   | Herbicides                  | Herbicides, Fungicides                               | Fungicides                                             |
| Market oriented                 | Moderate–High               | Moderate–High                                        | Herbicides<br>Moderate–High                            |
| Land scarce                     | Insecticides, Herbicides    | All chemicals                                        | All chemicals                                          |
| Market oriented                 | High                        | High                                                 | High                                                   |

Note: Market shares of agrochemicals are broadly consistent with the above typology of countries and cropping systems.

agricultural intensification with high use of traded inputs. The demand for all chemicals is high in such societies.

While cereals command the highest share of the insecticide market, per hectare application levels are the lowest. Fruit and vegetables have the highest per hectare application rates of insecticides and fungicides. For high-value crops such as fruit and vegetables, the price premium for an unblemished physical appearance is substantial. Risk-averse farmers tend to apply pesticides heavily to capture this price differential. In the case of rice, the most important cereal crop in Asia, pesticides do not enhance physical quality in any way, and there is no price differential to capture (Rola and Pingali, 1993). Given the positive income elasticity of demand for fruit and vegetables, the long-term prognosis for developing economies is one of increasing areas under these crops and, in the absence of alternative pest control strategies, an increasing share of the agrochemical market.

#### 14.2.3. *Perceptions of Pest Problems and Pesticide Use Practices*

In an extensive review of case studies from across Asia, Rola and Pingali provide documentation that policy-maker perceptions of yield losses are higher than

farmer perceptions of yield losses, which in turn are higher than actual yield losses. Both farmer and policy-maker perceptions of pest-related yield losses are anchored around exceptionally high losses during major infestations, even when the probability of such infestation is low. Improved farmer experience and education, especially through targeted training courses, could help farmers evaluate pest related yield losses more realistically and reduce pesticide use (Pingali and Carlson, 1985). Similar efforts to improve policy-maker perceptions could help reduce the reliance on pesticides as the only viable method of pest control.

Even where perceptions on yield losses and on the efficacy of pesticide use are relatively accurate, farmer knowledge on appropriate safety practices and the adverse consequences of pesticide use tends to be limited.

The literature abounds with evidences of third world farmers using pesticides unsafely and injudiciously (see, for instance, Bull, 1982; Boardman, 1986; Rola and Pingali, 1993; Chapter 3). Acute poisoning in Philippine rice farm households can be traced to unsafe practices in handling, storing, and disposing of pesticides for several reasons. First, even if farmers are aware of the hazards, they cannot afford appropriate clothing, adequate storage, and disposal systems. Most farmers, however, do not know about the consequences of mishandling chemicals. Hence farmer training on proper pesticide handling could minimize unnecessary exposure to chemicals.

The two other causes of pesticide exposure leading to poisoning are farmers' ignorance of reentry intervals and the use of defective sprayers. A reentry interval is the time needed to allow a chemical to dissipate in the environment. Most organophosphates (OPs) and organochlorines (OCs) used in the tropics have a reentry interval of at least seventy-two hours, but farmers usually go back the same day to see if the spray has worked (Rola and Pingali, 1993). It is also suspected that few manual weeders (traditionally women) know about the reentry interval requirement. In any case, no danger signs are posted on newly sprayed fields. Thus weeders as well as children and other household members in or nearby newly sprayed fields are directly exposed to pesticides. The knapsack sprayer is notorious for its mechanical defects and leakages, yet it is the most popular means of spraying pesticides in the developing world. Little has been done to improve the safety of this equipment.

#### *14.2.4. Productivity Benefits of Pesticide Use*

Discussion of the productivity benefits of pesticides revolves around the presumption that pesticides are a risk-reducing input—that is, the variability of yields are reduced. One needs to question this presumption, both for insecticides and for herbicides. In the case of insecticides, Rola and Pingali (1993) provide

empirical evidence for rice production that shows insecticide applications increase yield variability. Applying insecticides routinely, early in the crop season or on a schedule during the growing season (prophylactic application), disrupts the pest-predator balance. Predominant reliance on chemical control often leads to pest resurgence and frequent large-scale infestations. Rola and Pingali (1993) found, for rice, that “natural control” (not applying any insecticides), in association with varietal resistance, to be consistently more profitable than prophylactic treatments and economic thresholds. This result holds for both the risk-neutral and the risk-averse farmer.

In the case of herbicides, Pandey and Medd (1991) challenge the generalization of risk reduction made in the literature. They argue that an assessment of the source of risk is essential in determining whether herbicides are risk reducing or not. Where the efficacy of herbicides is certain and the weed-free yield distribution is stochastic, increased herbicide applications can increase variability in profits.

#### *14.2.5. Environmental and Health Impacts of Pesticides*

Careful measurement and documentation of the environmental and human health consequences of pesticide use is rare for developing country agriculture. In the case of rice, the International Rice Research Institute (IRRI) recently completed a detailed farm-level assessment in the Philippines of the long-term impacts of pesticides. A similar assessment is being done for potatoes at expand CIP in Ecuador (Crissman and Cole, 1994).

In the case of rice, Philippine evidence indicates that indiscriminate pesticide use can have serious environmental and health consequences. The environmental effects are primarily in terms of groundwater pollution, reduction of vertebrate populations in surface water systems, and the disruption of the long-term species equilibrium in the paddy ecosystem. At current levels of pesticide use and given that the chemicals used degrade rapidly in the humid tropical climate, the environmental effects are small, but one should not discount the potential for larger future effects.

The health effects of pesticide use in the Philippines are, however, quite substantial (Pingali, Marquez, and Palis, 1994; Rola and Pingali, 1993; Antle and Pingali, 1994). Eye, skin, pulmonary, and neurologic problems are significantly associated with long-term pesticide exposure. The majority of the pesticides that might be linked to these impairments, the highly hazardous category I and II chemicals, while commonly available in the Philippines, are banned or severely restricted in the developed world. Rola and Pingali (1993) found that the net benefits of pesticide use are negative when health effects are explicitly

accounted for. Antle and Pingali (1994) found that pesticide-related health impairments cut farm household productivity. When pesticide use is reduced, the value of the positive health benefit of reduced pesticide exposure is invariably greater than the value of the crop lost to pests.

#### ***14.2.6. Status of Technological Alternatives to Pesticides***

In the short term, the use of pesticides may still be necessary especially in nonrice crops where some quality-enhancing effects bring higher profits. In rice, however, the development of host plant resistance and integrated pest management (IPM) strategies would minimize, if not totally eradicate the use of pesticides in the longer term.

Technology for IPM that recognizes the receptivity of different farmer groups has been developed but is not widely available. More constraining than the availability of technology is the lack of facilities and support services for extension personnel to do their work. Many countries do not have functional IPM extension programs because the people who would participate in them have no means of travel to farms or demonstration sites.

In a related problem, few national programs have scientists who can generate the IPM technology themselves. Few scientists have been exposed to contemporary knowledge on IPM, and few guidelines exist on the extrapolation domain of IPM technology generated at one locality for use in another (Teng, 1990).

The use of IPM strategies in developed countries as the United States has been made possible by a wide variety of public initiatives. Land grant universities have been responsible for developing IPM strategies, for evaluating alternative strategies, and for popularizing the “best” strategies in the farm community. Continued use of IPM in some areas depends on public provision of advising services; the supply of pest control advisors is similarly dependent on the training capacity of land grant universities (Lichtenberg, Pingali, and Spear, 1991). At this time the IPM research and extension infrastructures is lacking in developing economies like the Philippines.

### **14.3. International and National Regulatory Mechanisms and Institutions**

#### ***14.3.1. International Regulatory Mechanisms***

In his discussion on the political economy of pesticides, Boardman (1986) noted that the regulatory environment has become an increasingly important factor in

the development or production of pesticides by companies. In turn, industry structures have both set limits to and provided opportunities for regulatory innovations by governments.

In the 1980s and 90s, growing environmental movements in developing economies have led to a growth in regulatory agencies and increasing pesticide restrictions. There are at least three general groups involved in regulating the international pesticide industry. These are (1) the self-regulatory body of the industry itself called the GIFAP, (2) intergovernmental organizations such as the UN, and (3) the interest groups such as the Pesticide Action Network (PAN).

**14.3.1.1. The Groupment International des Association Nationales de Fabricants de Produits Agrochimiques (GIFAP).** The general objective of this organization is to protect the interests of the world pesticide industry. GIFAP lobbies against excessive regulation of the industry and projects the industry perspective in public debates. It has also been very effective in protecting industrial patents and property rights and in monitoring product quality. For instance, in the early 1980s, GIFAP pressed for withdrawal of most-favored nation status for Hungary because of an alleged lack of respect for chemical patents by that country (Boardman, 1986).

**14.3.1.2. Intergovernmental Organizations.** Among the intergovernmental organizations, the United Nations Food and Agriculture Organization (FAO) and the World Health Organization (WHO) have taken active roles in international pesticide regulations since the 1950s. The two were joint founders of the Codex Alimentarius Commission, designed in the early 1960s as a body to oversee and promote improvements in food standards in their various member states. The Codex Committee on Pesticide Residues has set standard values for maximum residue levels in food and the environment that could be used as a guide by national agencies as regulatory measures. However, there is a lackluster response to the Codex by national agencies basically because of the high cost of residue monitoring. Also, national regulatory priorities are weighed more heavily towards occupational safety rather than monitoring food quality.

In addition, the WHO has designed hazard classifications for different classes of compounds, where category I is considered extremely hazardous, while category IV the least hazardous. Most organochlorines (OCs) and organophosphates (OPs) are in category I classification (with oral and dermal 50 values). This hazard classification could potentially help countries determine the types of chemicals they would like to import and register.

The FAO on the other hand drafted the International Code of Conduct on the distribution and use of pesticides (FAO, 1986). The code calls on the pesticide



industry at all levels, as well as exporting nations, international agencies, and public-sector organizations, to assume a share of responsibility for ensuring safety in the use of pesticides. The code's provisions are entirely voluntary, and there has been considerable controversy over the extent to which they are respected in practice (Loevinsohn, 1993). Loevinsohn (1993) also reports widespread infringements of the code as evidence is presented regarding misleading advertising, inappropriate packaging, poor quality control, and marketing of banned and dangerous products.

Together with the United Nations Environmental Program (UNEP), FAO has adopted another regulatory scheme based on the principle of prior informed consent (PIC). In this scheme, a designated authority in the importing country must explicitly agree to the import before it can take place. In the PIC scheme, the importing country will be given the information about the registration status of chemicals in other countries. Pesticides banned or severely restricted in five or more countries will be included in the PIC list, and importing countries will be informed of such.

This scheme hinges on the importing government's ability to evaluate and act on the notices it receives. But this capacity is deficient in many developing countries. And as Loevinsohn (1993) has stressed, PIC begins with the decisions industrialized countries have taken to protect health and the environment within their own jurisdictions. However, industry has often claimed that a different balance of risks and benefits may lead developing countries to judge acceptable a number of pesticides strictly controlled in industrialized countries (Willis, 1986). The ultimate goal of the PIC is to provide information to national agencies regarding the chemicals being traded so that they can make a rational choice.

**14.3.1.3. Nongovernment Organizations.** Several multipurpose environmental nongovernmental organizations have also been concerned with pesticide issues. Among these are the International Union for Conservation of Nature and Natural Resources (IUCN), and some regional organized transgroupings such as the European Environmental Bureau (EEB), or the Pesticide Action Network (PAN) of the International Organization of Consumers Unions (IOCU). With support from many developing countries, these NGOs have mounted lobbying effort in regulatory bodies. For instance, they have worked with governing councils of FAO and UNEP to push the PIC process in developing economies. However, certain realities have to be contended with.

The United States, United Kingdom, and European Community have instituted schemes to notify importing countries of shipments of unregistered or severely restricted pesticides. In practice, however, notification are often received well after the pesticides have arrived and do little to enable importing countries to control hazardous imports (Pallenaerts, 1988). The future state of communications

technology and governments' stringent regulations could improve this situation and move forward to the preferred state of safe chemical use.

#### **14.3.2. *Developing Countries' Regulatory Capabilities***

In most developing countries, increasing use of pesticides can be directly attributed to agricultural modernization programs. In the Philippines, the spread of irrigated rice agriculture in the 1960s triggered the development of a full-blown pesticide industry. Pesticides in most developing countries are imported as it is very expensive to develop raw materials.

Pesticide regulations in developing countries lack uniformity of approaches, as observed by Boardman (1986). It was only during the 1970s that many countries began to think about regulatory requirements. In the Philippines, for instance, the regulatory body instituted in 1978 was originally given the control of the importation, manufacture, formulation, distribution, sale, transport, storage, labeling, use, and disposal of pesticides and fertilizer. Today, this agency is mandated to register new pesticides, regulate pesticide availability and use, license handlers, set residue limits on food and feed, monitor compliance of regulatory policies, supervise imports, and design pesticide-training programs. In the Philippines as in most developing economies, enforcement capabilities more often lag behind laws and regulations or, in the extreme, could be non-existent. Complexity of the regulations and the high resource requirements for enforcement have jointly contributed to the failure of past regulatory efforts.

### **14.4. Preferred Scenario for Pesticide Use**

An optimal pesticide policy revolves around possible ways of ensuring its effective use—that is, of promoting agricultural productivity while minimizing the health and environmental effects. The following are the elements of a preferred scenario for pesticide use.

#### **14.4.1. *Judicious and Safe Use of Chemicals***

The movement away from prophylactic pesticide applications to a holistic management of the plant, pest, and predator system will reduce pesticide requirements, even for intensively cultivated systems. However, integrated controls are knowledge intensive and location specific; they require substantial allocations of technical and administrative resources in farmer training and

extension programs. Farmer training ought to also include safety procedures in handling, storage, and disposal of chemicals.

#### ***74.4.2. The Substitution of the Less Hazardous Category III and IV Chemicals for the More Hazardous Category I and II Chemicals***

Evidence from the developed world and more recently from the developing world indicates that there is no productivity loss in substituting category I and II chemicals with category III and IV chemicals. In fact, if the health gain associated with reduced exposure to the highly hazardous chemicals is accounted for, then there could actually be a net productivity gain in the switch to category III and IV chemicals. The opportunities for selective banning or taxation are discussed below.

#### ***14.4.3. Improved Understanding of the Productivity, Health, and Environmental Impacts of Agrochemicals***

In registering or reregistering pesticides for use in a country, the regulatory agency ought to have an improved understanding of the productivity benefits as well as the risks of pesticide use. Risk-benefit assessment is the appropriate analytical tool for making such decisions. While country-specific measurements of impacts would give the most accurate technical coefficients for risk assessment, the value of similar information collected elsewhere should not be discounted, at least in a prior probability sense. An improved understanding of the tradeoffs would allow the regulatory agency to be more discriminatory in its choice of chemicals to import or register. Farmers with improved knowledge of consequences of pesticide use could be equally discriminating in their choice of pest control strategies.

#### ***74.4.4. Improved and Standardized Spray Equipment***

Factors leading to the continued production of inferior sprayers include the lack of incentives for local manufacturers to produce good quality sprayer, farmers' poor appreciation of quality and safety features and the lack of national minimum product standards (Mamat, Jusah, Anas and Sarif Hashim). To overcome these problems would require the establishment of research programs in national agricultural research institutes to design safer and more efficient knapsack sprayers

that can be produced locally, upgrade farmers' knowledge and improve their appreciation of good-quality sprayers and safer spraying practices, and regulatory agencies establishing minimum standards for knapsack sprayers.

#### ***14.4.5. Industry's Corporate Responsibility***

There are at least two critical areas that industry could target with regard to enhancing safety. One is the promotion of safer pesticides, and second is the safe packaging and proper labeling of products for farmers' use.

The corporate sector ought to expect that as incomes grow in the developing world, the demand for safer pesticides will increase just as it did in the developed world. This shift will come not only from the emerging environmental lobbies in these countries but also from increasingly safety conscious farmers. The challenge for the industry is to reduce the unit cost of production of the less hazardous chemicals and thereby price them at levels comparable to the more hazardous but cheaper category I and II products.

On the matter of packaging, major changes occurred during the 1980s and further progress is expected during the 1990s. Recent advances in plastics and molding technology have made pesticide containers safer in the developed world. Manufacture of these in the developing world is still limited. Returnable containers are now commonly used in the United States and Europe. Made of stainless steel or plastics, they can be returned to the supplier for refilling. This eliminates the problems of container misuse and disposal. However, this approach requires a good supply and transport infrastructure, often lacking in developing countries (Dollimore, 1993). Further, potential use of water-soluble sockets has also occurred as this technology has improved. Although these sockets were originally designed to contain powders, they are now being used for liquid formulation. Again such technology is expensive for developing economies. With respect to labeling, while FAO/WHO have issued standards (FAO, 1986), their adoption and implementation by member countries is poor. User friendly labels could significantly reduce the risks faced by farm households.

### **14.5. Regulatory Options for Safer Pesticide Use**

Several regulatory options are available for moving toward the preferred scenario of safer and reduced pesticide use. Some of these are discussed below. It ought to be recognized, however, that the most effective means of regulatory control are pesticide registration and taxes. The costs of enforcement are substantially higher for all other options.

### *14.5.1. Banning Certain Chemicals*

The current regulatory debate in developing countries is on whether the importation of the highly hazardous category I and II chemicals ought to be banned. In developed countries, the registration of many of these chemicals has been cancelled or has been allowed under very restricted conditions. The U.S. evidence of a ban on the use of certain pesticides has shown that although the initial impact is of a decrease in output supply, in the long run and with additional land the fall in supply is small (Lichtenberg, Pingali, and Spear, 1991). Eliminating fifty-seven chemicals in Indonesia has not led to a fall in food supply. The resulting change in the relative price of pesticides led to an increase in the use of alternative nonchemical methods and integrated controls, such as use of IPM.

The Indonesian experience allows us to question the traditional argument about pesticide cancellation: that it always leads to “technological regression” and therefore a decrease in output supply (Just, Hueth, and Schmitz, 1982). This argument assumes limited substitution opportunities across chemicals and even smaller possibilities for substitution among chemical and nonchemical methods of pest control. Neither assumption is valid. Moreover, the Indonesian experience has shown that the cancellation of broad-spectrum insecticides has improved the pest-predator balance, prevented pest resurgences, and therefore increased the productivity of the pesticides applied (Rola and Pingali, 1993).

Where opportunities for input substitution are not available, Lichtenberg, Pingali and Spear (1991) argue that pesticide bans increase the comparative advantage of regions that are less vulnerable to pest infestations or better suited to alternative means of pest control. For example, fruit and vegetable production in hot and humid climates is susceptible to high disease pressure, pesticide bans would result in the movement of this production elsewhere. The positive connotation of this argument is that the hot and humid tropics will concentrate on crops that are more suited to that environment and hence less susceptible to pest pressures.

### *14.5.2. Tariffs and Taxes*

Price and tariff interventions could be used to encourage the shift to safer chemicals and to nonchemical pest control practices. Very high tariffs especially on pesticides on the PIC list could discourage importers from promoting these chemicals. Very high rates of taxes of category I and II versus the category III and IV could encourage the farmer to shift to safer chemicals.

Antle and Pingali (1994) provide simulation results for rice production to show that, while a uniform tax on insecticides and herbicides has negative effects on productivity, a tax on insecticides alone has a significant positive effect on productivity. Insecticides used in the Philippines are the highly hazardous category I and II chemicals. A reduction in the use of these chemicals has significant positive farmer health benefits, which leads to an increase in productivity. The loss in productivity resulting from increased pest-related yield losses is more than offset by the gain in productivity from improved health. The social benefits of restricting insecticide use are substantially higher than the social costs. The same argument does not hold for herbicides, because: (1) herbicides used are, generally, the less toxic category III and IV chemicals, therefore the health benefits are smaller, and (2) the yield response to herbicide use is substantially higher than the response to insecticide use.

#### *14.5.3. Monitoring Residue Tolerance Limits*

Following the lead of developed country regulatory agencies, several developing countries have set up pesticide residue monitoring units. These units are meant to track residue levels in food, water, and in some cases long-term buildup of pesticides in the soil. In general, pesticide-residue monitoring tends to be resource intensive and not very effective.

Monitoring of internationally traded food products is the only viable residue-screening activity. In this case, however, producers themselves have an incentive to adhere to international standards. In the case of domestically traded food products, however, in a developing country context, the sheer volume of producers and the large number of market outlets makes monitoring quality exorbitantly expensive and nonviable.

If the regulatory objective is to make food supplies and the environment safer, then there are more effective means of achieving it than residue monitoring. A three-pronged approach aimed at producers would be (1) cancellation of the highly hazardous or persistent chemicals, (2) selective taxation to make the liberal use of all chemicals expensive, and (3) farmer training in the judicious and discriminate use of chemicals.

#### *14.5.4. Enforcing Pesticide Safety Standards*

Safety standards can cover the broad spectrum of activities associated with the use and handling of pesticides. This includes sales, storage, application, and

disposal. The most effective means of setting these standards is through clear labeling—verbal or pictograms. Labels can help farmers discriminate among chemicals and help provide them information on appropriate use and disposal. Regulation via verbal labels is effective only in highly literate societies. Pictograms are an alternative for less literate societies; however, since these may not be universally understood, especially in the developing world, more education and mass communication are needed. Hence, label regulation is effective only if complimentary investments are made in training farmers to read and interpret them.

In developing countries, substantially greater resources have to be devoted to monitoring product quality at the retail level. Comparisons of label information with the contents of the pesticide bottle have revealed substantial variability in the type and the quality of the material. Regulatory control of dealers, through appropriate licensing, training, and monitoring, not only could improve the efficacy of the compounds but also could safeguard environmental and human health.

As mentioned earlier, application equipment should meet the minimum international standards. This would reduce farmer risk of unnecessary exposure to pesticides. Equipment with good nozzles and that is properly calibrated promotes efficient use of chemicals and avoids drift. Finally, substantial future work needs to be done on comfortable and affordable protective clothing for the farmer-sprayer. There is enough evidence to show that protective clothing from the temperate countries cannot be easily adapted to tropical conditions (Chester et al., 1993).

## 14.6. Conclusions

We would like to conclude this paper by returning to the three questions we posed in the introduction: (1) should poor countries divert resources toward environmental protection; (2) do countries face a tradeoff between productivity growth and environmental protection; and (3) are developed country regulatory policies appropriate for and transferable to developing countries?

Poor countries do need to be concerned with environmental protection, in the case of pesticides, for several reasons. First, pesticide related externalities have a negative effect on productivity, especially the reduction in labor productivity resulting from impaired health due to direct and indirect exposure to pesticides. Second, indiscriminate pesticide use can have long-term negative consequences on the farm environment, especially in terms of disturbing the ecological balance. For instance, prophylactic insecticide applications can disrupt the pest-predator balance in favor of pests and thereby lead to a buildup of these populations in intensive monoculture systems. Third, countries do not remain

poor forever, as incomes grow the demand for improved environmental quality increases, regulatory policy ought to be forward looking and anticipate this increased demand.

It is not possible to make a generalization regarding the tradeoff between productivity and environmental protection that could result from pesticide regulation. In the case of rice, with the progress made in varietal resistance, the trade off is small. In the case of vegetables, where the progress in varietal resistance has been slow and physical appearance commands a price premium, the tradeoff can be high. Detailed crop-by-crop assessments are needed to determine the magnitude of the productivity tradeoff.

On the transferability of developed country regulations to developing countries, one can argue that direct transfers are generally not appropriate. The goals and objectives of developed country regulatory policies are often different from those of developing countries. For instance, developed countries tend to be more concerned with food safety and hence emphasize residue monitoring, while developing countries would be more interested in reducing health hazards associated with pesticide exposure. There is no unique recipe for pesticide regulation. Each country would have to determine their unique set of regulations based on needs, financial resources, and enforcement capabilities.

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# Appendices



# APPENDIX A

## ANNOTATED BIBLIOGRAPHY ON THE FATE OF PESTICIDES IN RICEFIELDS AND RICEFIELD SOILS

P.A. Roger

This annotated bibliography of 136 references deals with the degradation/persistence of pesticides in ricefields and ricefield soils. Papers selected include:

- Papers reporting studies in ricefields, with ricefield soil, or with strains isolated from ricefields or known to be present in ricefields;
- Few papers of interest for methodological aspects or presenting data useful for comparison; and
- Bibliographic reviews including references on wetland soils.

The list is not exhaustive. About sixty additional annotated references on the topic can be found in the following report: D.G. Crosby and S. Mabury (1992), *Management of pesticide residues in ricefield tailwater*, A report to the Soil Conservation Service of U.S. Department of Agriculture, Department of Environmental Toxicology, University of California, Davis, CA 95616, USA. 57 pp.

The following code is used:

- (NS) (No summary) The original paper has no summary.  
(NC) (Not consulted) The paper was not available and is cited from another paper.

**Abstract** The document cited is only an abstract, not a full paper.

**Summary** The summary or abstract included in the original paper.

**Notes** Short summary or comments by the author of this compilation.

Adhya, T.K., Sudhakar-Barik, Sethunathan N. (1981) Fate of fenitrothion, methyl parathion and parathion in anoxic sulfur-containing soil systems. *Pestic. Biochem. Physiol.* 16: 14. (NC)

Adhya, T.K., Sudhakar-Barik, Sethunathan N. (1981) Hydrolysis of selected organophosphorus insecticides by two bacteria isolated from flooded soils. *J. Appl. Bacteriol.* 50: 167. (NC)

Adhya, T.K., Sudhakar-Barik, Sethunathan N. (1981) Stability of commercial formulation of fenitrothion, methyl parathion and parathion in anaerobic soils. *J. Agric. Food Chem.* 29: 90-93.

**Summary:** The relative stability of formulated emulsifiable concentrates of fenitrothion, methyl parathion, and parathion in an anaerobic soil was studied by using two approaches. When the formulated pesticides were applied to ten-day preflooded soil, followed by continued incubation of soil samples under static flooded conditions, degradation of parathion proceeded essentially by nitro group reduction and of methyl parathion and fenitrothion by hydrolysis. In contrast, all three insecticides were degraded by nitro group reduction to their respective amino analogues in the second approach involving direct equilibration of the pesticide with the soil prereduced by flooding for different periods. Interestingly, rapid nitro group reduction of all organophosphates, parathion in particular, occurred within 5 s of their equilibration with a soil prereduced by incubation with rice straw under flooding. Sterilization of the prereduced soil by autoclaving prevented the rapid destruction of the pesticides by the prereduced soil.

Agnihotri, N.P. (1978) The degradation of pesticides in soil. Edwards C.A., Veeresh G.K., Krueger H.R. (eds.), Pages 343-356 in *Pesticide residues in the environment in India*. Proceedings of a symposium held on November 1978 at the University of Agricultural Sciences, Hebbal Bangalore India under the auspices of FAO/UNESCO/UNDP/ICAR/UAS. 524 p.

**Notes:** Laboratory and field experiment using flooded and nonflooded soils. Degradation of disulfon and phorate in soil alone was slightly slower when fertilizer was added, however, *in situ* degradation was faster when fertilizer was applied because of a better plant growth in the treated plots.

Aquino, G.B., Pathak, M.D. (1976) Enhanced absorption and persistence of carbofuran and chlordimeform in rice plant on root zone application under flooded conditions. *J. Econ. Entomol.* 69: 686–690.(NC)

*Notes:* cf. Pathak et al. (1974)

Arita, H., Kuwatsuka, S. (1991) Relationships between the degradation rate of the herbicide pyrazofen and soil properties. *J. of Pest. Sci.* 16(1): 71–76.

*Summary:* A comparison was made by laboratory experiments of the degradation rate of  $^{14}\text{C}$ -labeled pyrazoxyfen in five paddy soils (collected from Tochigi, Ibaraki, Nagano, Anjo, (Aichi) and Fukuaoka) under simulated upland (moisture adjusted to 50 percent of the maximum water holding capacity) or flooding (covered with 1 cm of water) conditions. Pyrazoxyfen degraded faster in the mineral soils (Fukuaoka > Anjo > Nagano) than in the humic volcanic ashes (Ibaraki > Tochigi), exhibiting a half-life of 3–5 and 5–34 days in the respective soils. When compared in the same soil, degradation was generally faster under flooded than upland conditions (half life of < 10 and 3–34 days respectively). Pyrazoxyfen degradation rate was negatively correlated with soil cation exchange capacity, OM content, C/N ratio and water holding capacity.

Au, L.A. (1980) Pesticide interactions in the laboratory rice paddy model ecosystem. *Diss. Abstr. Int. B* 40: 3567–3568.

*Notes:* Model ecosystem (Microcosm) to study the impact of combinations of pesticides. Do not include microbiological measurements. Combination of methyl parathion with atrazine substantially decreased the degradation of both pesticides in the roots of rice and increased their persistence in the water and soil phase of the model.

Bardsley, C.E., Savage, K.E., Walker, J.C. (1968) Trifluralin behavior in soil: II Volatilization as influenced by concentration, time, soil moisture content, and placement. *Agron. J.* 60: 89–92.

*Notes:* Trifluralin can be extensively lost by volatilization depending upon concentration, mode of application and moisture content of the soil.

Brahmaprakash, G.P., Reddy, B.R., Sethunathan, N. (1985) Persistence of hexachloro-cyclohexane isomers in soil planted with rice and in rice rhizosphere soil suspensions. *Biol. Fert. Soils* 1: 103–109.

*Summary:* The relative persistence of alpha, beta and gamma-isomers of hexachlorocyclo hexane (HCH) was studied in a flooded soil with and without



rice seedlings under greenhouse conditions. Beta-HCH was more stable than alpha- and gamma-HCH in both planted and unplanted systems. Alpha- and gamma-HCH decreased to negligible levels (5.5 percent for the alpha-isomer and 2.4 percent for the gamma-isomer) after thirty days in planted and unplanted soils. During the same period, 30.9 percent of the added beta-HCH was recovered from planted soil and 50.6 percent from unplanted soil. Likewise, in anaerobically ( $H_2 + CO_2$  atmosphere) incubated mineral salts solution inoculated with suspensions from rice rhizosphere and non-rhizosphere soils. Gamma-HCH decreased to low levels ( $< 15$  percent) within five days. Most of the added beta-HCH was recovered from mineral solution inoculated with nonrhizosphere soil suspension even after thirty days while beta-HCH decreased to 53.6 percent of the original level in mineral solution inoculated with rice rhizosphere soil suspension. The data reveal that the degradation of anaerobically unstable HCH isomers is not retarded by the possible aeration of a flooded soil by rice roots.

Castro, T.F., Yoshida, T. (1971) Degradation of organochlorine insecticides in flooded soils in the Philippines. *J. Agric. Food Chem.* 19: 1168–1170.

*Summary:* The effect of organic matter in the biodegradation of the organochlorine insecticides DDT, endrin, heptachlor, and the four isomers of BHC was studied in two soils under submerged soil condition. The four insecticides were found to degrade biologically at a faster rate in nonsterilized than in sterilized soil. Adding organic matter to the soil seems to increase its organic chemical adsorption in the control soil. When the soil has a relatively high content of organic matter, addition of more organic matter seems to have no effect. When the soil has little organic matter, however, a more pronounced effect is obtained.

Chen, S.J., Hsu, Err-Lieh, Chen, Y.L. (1982) Fate of the herbicide benthioncarb (Thiobencarb) in a rice paddy model ecosystem. *J. Pest. Sci.* 7: 335–340.

*Summary:* The metabolic fate of benthioncarb (thiobencarb) was studied with  $^{14}C$ -labeled compound by a rice paddy model ecosystem in the laboratory. In addition to rice plants, ten organisms including grasshopper, rice brown planthopper, mosquito larva, wolf spider, water flea, dragonfly naiad, giant duckweed, mosquito fish, alga, and paddy snail were involved in this ecosystem. The radioactivity extracted with n-hexane from water, sand and biota at the end of experiment (twenty-three days after the application of  $^{14}C$ -benthioncarb) corresponded to 2.73 percent, 23.18 percent, and 0.31 percent of the initial radioactivity applied, respectively. Metabolic fate of benthioncarb in these organisms was studied. Some unknown metabolites were detected beside several known ones. From its low ecological magnification values on the aquatic organisms and high biodegradability indices for these biota, benthioncarb was found to be safe

from an environmental standpoint. This rice paddy model ecosystem seemed to be very effective and useful for studying the fate of pesticides in the environment, especially in paddy fields.

*Notes:* Sand is used instead of rice soil which might have biased the results.

Chen, Y.L. (1980) Degradation of butachlor in paddy fields. Pages 121–141 in *FFTC Book Series No. 20, Weeds and weed control in Asia*. Food and Fertilizer Technology Center, Taiwan. (NS)

*Notes:* Extensive experimental survey of all pathways of butachlor disparition from ricefields. Includes data on its effect on nitrification at different temperatures and pH. At 30°C and pH 6.8, 6 ppm butachlor simulated nitrification, soil respiration, had no significant effect on populations of fungi and actinomycetes but possibly increased total populations of bacteria for about two weeks.

Del Rosario, D.A., Yoshida, T. (1976) BHC and DDT residues of some rice crops and soils in the Philippines. *Soil Sci. Plant Nutr.* 22(1): 81–87.

*Summary:* Rice seed, plant, and soil samples from the provinces of Iloilo, Bulacan, Nueva Ecija, and Mountain Province, and Palawan in the Philippines were analyzed for the presence of the four BHC isomers and of DDT. Low levels of the four BHC isomers were detected in all the samples. The plants generally had a higher BHC content than the soil. The amounts of BHC found in the grain and hull were below the tolerance limit set by the United States Food and Drug Administration. DDT and its metabolites were identified in Palawan and the Mountain Province. The presence of DDT in the samples could have been due to the contamination from the DDT sprayed for malaria control in the dwelling places where the rice was stored.

Deuel, L.E., Turner, F.T., Brown, K.W., Price, J.D. (1978) Persistence and factors affecting dissipation of molinate under flooded rice culture. *J. Environ. Qual.* 7(3): 373–377.

*Summary:* Pesticides, essential for the economical production of rice (*Oryza sativa* L.), could pose a serious problem if transported to surface impoundments and estuaries along the Gulf Coast via the return flow associated with flooded rice culture. Field experiments were conducted under flooded rice cultivation to determine persistence and half-life of molinate (Sethyl-hexahydro-1-H-azepine 1–1carbothioate). Persistence and half-life were evaluated with respect to intermittent and continuous flow irrigation schemes at normal and excessive application rates of 3.4 and 11.2 kg/ha molinate, respectively. Persistence at statistically significant levels ranged from 96 to 384 hours following the application, and

generally was more a function of the application rate than irrigation scheme. Half-life values averaged  $96 \pm 22$  hours in intermittent flow plots, and  $54 \pm 17$  hours in continuous flow plots over the three-year experiment. Application rate had little effect on half-life. Best fit analysis of field data to the first order biological decay equation and laboratory studies under flooded soil conditions suggested that biological degradation was the principle mode by which molinate was dissipated in the field experiment.

Fereria, J., Raghu, K. (1981) Decontamination of hexachlorocyclohexane isomers in soil by green manure application. *Environ. Tech. Lett.* 2: 357–364.

*Summary:* Application of green manure to flooded rice soils resulted in enhanced degradation of all four isomers of hexachlorocyclohexane (HCH) including the most persistent beta isomer. This suggest the possibility of using this agricultural practice for lowering the residue levels of HCH in soil.

Fox, J. L. (1983) Soil microbes pose problems for pesticides. *Science* 221: 1029–1031. (NS)

*Notes:* Short review on the problem of pesticide inactivation by adaptive soil microflora.

Funayama, S., Uchida, M., Kanno, H., Tsuchiya, K. (1986) Degradation of buprofezin in flooded and upland soils under laboratory conditions. *J. Pest. Sci.* 11: 605–610.

*Notes:* Buprofezin gradually decomposed in soils under flooded and upland conditions, with half lives of 104 and 80 days respectively. Degradation products were identified. Degradation was markedly reduced in sterile soil. The authors concluded that buprofezin seems to undergone complete mineralization by microorganisms in both submerged and non-submerged soils.

Gill, S.S., Yeoh, C.L. (1980) Degradation of carbaryl in three components of the paddy-field ecosystem of Malaysia. Pages 229–243 in *Agrochemical residue: Biota interactions in soil and aquatic ecosystems*. Proceedings of a Joint workshop, FAO/IAEA, IAEA, Vienna.

*Summary:* The degradation of carbaryl in soil, soil extract and the paddy-field *Trichogaster pectoralis* was studied. In Kundor soil, under flooded conditions, carbaryl had a half-life of about seven weeks. The formation of the major degradation product, 1-naphthol, correlated with the disappearance of carbaryl. 1-Naphthyl-N-hydroxymethylcarbamate, 4 and 5-hydrocarbaryl were also formed. The rate of degradation of carbaryl was dependent on the moisture level and the

presence of microorganisms. Carbaryl was relatively more persistent in acid sulphate soils than normal (Kundor) paddy-field soil. Carbaryl underwent a similar degradation in water extracts of soil. Degradation of carbaryl by the liver of *T. pectoralis*, however, followed a slightly different pathway with 1-naphthyl-N-hydroxymethylcarbamate being the major product. The other products formed include 1-naphthol, 5-hydroxycarbaryl and three unidentified metabolites.

Gowda, T.K.S., Sethunathan, N. (1976) Persistence of endrin in Indian rice soils under flooded conditions. *J. Agric. Food Chem.* 24: 750–753.

*Summary:* A radiotracer study was conducted to determine the relative persistence of endrin-<sup>14</sup>C under flooded conditions in eight Indian rice soils. Endrin decomposed rapidly and reached low levels within fifty-five days in all soils except in a sandy soil. Interestingly, most rapid degradation occurred in pokkali soil despite its high salt content. The decrease in the total radioactivity partitioned in the chloroform-diethyl ether fraction was less pronounced despite the rapid decline in endrin levels indicating the formation of stable metabolites. Radioautography reveals that endrin was converted to six stable metabolites in all soils except in sandy and kari soils; five compounds were detected in kari soil and three compounds in sandy soil. More rapid degradation of endrin occurred in nonautoclaved samples of three soil types than in autoclaved samples indicating microbial participation in its degradation. The addition of rice straw enhanced the degradation of endrin. Liming the acid soils had no effect on the degradation rate of endrin.

Gowda, T.K.S., Sethunathan, N. (1977) Endrin decomposition in soils as influenced by aerobic and anaerobic conditions. *Soil Sci.* 124: 5–9.

*Summary:* The relative persistence of endrin in soils as related to flooding and alternate “anaerobic” (flooded unstirred) and “aerobic” (flooded stirred) conditions was studied in three soils by radiotracer technique. More rapid degradation of endrin occurred in all three soils under flooded conditions than under nonflooded conditions. Autoradiography revealed the formation of six breakdown products in flooded soils as compared to four compounds in nonflooded soils after twenty-five days of incubation. The breakdown products, detected at the end of twenty-five days of preincubation under flooded unstirred (predominantly anaerobic) conditions, decreased to low levels following incubation under unstirred conditions for another thirty days. By contrast, when the flooded soils were stirred for thirty days after twenty-five days of unstirred conditions, undecomposed endrin and some of its breakdown products detected at the end of unstirred conditions persisted and accumulated. The data demonstrated that aerobic conditions in

nonflooded soils and in flooded soils subjected to an unstirred-stirred cycle increased the persistence of endrin and its breakdown products.

Guenzi, W.D., Beard, W.E. (1976) The effects of temperature and soil and water on conversion of DDT to DDE in soil. *J. Environ. Qual.* 5: 243–246.

*Notes:* High temperature decreases adsorption and favor desorption of pesticides, which may result in higher quantities of pesticides dissolved in soil water and a faster disposition.

Heritage, A.D., MacRae, I.C. (1979) Degradation of hexachlorocyclohexane and structurally related substrates by *Clostridium sphenoides*. *Austr. J. Biol. Sci.* 32–493. (NC)

*Notes:* Demonstration of the ability of a strain isolated from an anaerobic soil to degrade HCH.

Higashi, R.M. (1987) Modelling the environmental fate of rice herbicides. Ph.D. Thesis. Agricultural and Environmental Chemistry. University of California, Davis. 109 p.

*Summary:* The California ricefield is a unique environment in which to study the chemistry of environmental fate. Under certain circumstances, the newly flooded rice paddy has well-defined physical and chemical characteristics due to relatively few biological interactions, static water, static soil-water, and the yearly application of large amounts of agrochemicals which can serve as study chemicals. These conditions limit the processes of dissipation from the water to soil adsorption, volatilization, and thermal/photochemical breakdown. In spite of the simplified situation, the ricefields are very dynamic with large diurnal variations forces such as pH, temperature, UV light, and dissolved oxygen. A dynamic approach to microcosm modeling aims to mimic the actual field profiles, thereby normalizing or otherwise accounting for the variable rates caused by the cycling of these forces. A physical-chemical microcosm with airflow, light and temperature under computer control was constructed and used to study the volatilization of molinate and the photodissipation of bentazon. Microcosm studies of dissipation under field-mimicking conditions corresponded much better to the field studies than under average, steady-state conditions. For molinate, the microcosm successfully reproduced field dissipation rates to within + 15 percent, whereas the conventional steady-state experiment yielded results that was fourfold too short, the discrepancy due to interaction between the granular formulation and the temperature profile. In the case of bentazon, the microcosm was able to mimic field dissipation from + 11 percent to + 113 percent, the greater discrep-

ancies using average temperature or laboratory water which consistently underestimated photodissipation rates as compared to varying temperature or field water. For one of the photoproducts of bentazon, diurnal and constant light gave results that drew opposite conclusions, namely that it does and does not accumulate, respectively. Again, the field-mimicking microcosm experiment (diurnal light) was closer to field observations. These findings point out the experimental conditions appropriate for the environment and dissipation mechanism(s) of the chemical—instead of standardized conditions—is crucial for estimations of persistence. Thus, dynamic microcosm studies, when are restricted to realistic field parameters, can converge on realistic estimations of persistence and fate of chemicals in the ever-changing environment.

Higashi, R.M., Crosby, D.G. (1987) A physical-chemical microcosm for ricefield environmental fate studies. Pages 445–448 in Greenhalgh R., Roberts T.R. (eds.), *Pesticide science and biotechnology*. Blackwell Scientific Publications, Oxford.

*Summary:* Physical-chemical microcosms can serve as a basis for prediction of persistence. The California flooded ricefield environment was modeled because of its well-defined history, relatively few biological interactions, and the large amounts of agrochemicals introduced into it yearly. We have constructed a computer-controlled aquatic microcosm to model volatilization and photolysis of the herbicides molinate and bentazon, respectively. Modeling was conducted with the dissipation forces (temperature and UV light) maintained both steady-state (field average) and profiled (diurnally varied as in a corresponding field study). Molinate dissipation in the steady-state microcosm (28°C,  $t_{1/2}$  = 1.60 days) was in discordance with experiments under profiled temperatures (18–32°C,  $t_{1/2}$  = 7.22 days), but the latter was similar to the field dissipation. This difference was attributed to an interaction of the profiled temperatures (16–28°C,  $t_{1/2}$  = 3.00 days) matched the field dissipation rate ( $t_{1/2}$  = 2.90 days) well, but was faster than the steady-state average temperature experiment (23.5°C,  $t_{1/2}$  = 4.12 days). In addition, cycling the UV light diurnally resulted in the persistence of a major photochemical product, although it did not accumulate under constant UV. These results indicate that accurate representation of variable field forces is essential for the development of a realistic microcosm system.

Hill, I.R. (1978) Microbial transformation of pesticides. Pages 139–202 in Hill, I.R., Wright, S.J.L. (eds.), *Pesticide microbiology*. Academic Press, London. 844 p.

*Notes:* A review that covers mostly the chemistry of pesticide decomposition. 334 references. Only six references refer specifically to flooded soils.

Hill, I.R., Wright, S.J.L. (1978) The behavior and fate of pesticides in microbial environments. Pages 79–136 in Hill, I.R., Wright, S.J.L. (eds.), *Pesticide microbiology*. Academic Press, London. 844 p.

*Notes:* A review with about 280 references. References on freshwater and anaerobic ecosystems are useful for understanding pesticide fate in wetland rice soils.

Ide, A., Niki, Y., Sakamoto, F., Watanabe, I., Watanabe, H. (1972) Decomposition of pentachlorophenol in paddy soil. *Agric. Biol. Chem.* 36: 1937–1944. (NC)

Isensee, A.R., Kaufman, D.D., Jones, G.E. (1982) Fate of 3,4-Dichloroaniline in a rice (*Oryza sativa*)—paddy microecosystem. *Weed Sci.* 30: 608–613.

*Summary:* The fate of 3,4-dichloroaniline (DCA), a major metabolite of the herbicide propanil (3',4'-dichloropropionanilide), in rice (*Oryza sativa* L.), soil, water and aquatic organisms was determined in rice-paddy microecosystems. Soil, treated with 10 ppm DCA, was placed in glass chambers, planted to rice, then flooded when the rice reached the two-leaf stage. After flooding, four species of aquatic organisms were added. The concentration of DCA and metabolites in soil, rice, water, and aquatic organisms was determined over a period of time. A maximum of 2.8 percent of the total radioactivity applied to soil desorbed or leached into water. DCA recovered from water decreased from 12 to 1 percent of the total radioactivity in water between 1 and 30 days after flooding. Between 10.5 and 18.5 percent of the radioactivity remaining in soil at the end of the experiments was extractable. Of the radioactivity recovered, between 5 and 11 percent was DCA, and up to 6 to 19 percent was 3,3', 4'4'-tetrachloroazobenzene (TCAB), these percentages being dependent on exposure time. Rice accumulated 0.5 percent or less of the total radioactivity in soil. Only 35 to 55 percent of the accumulated radioactivity was extractable. Very small amount of radioactivity were accumulated by aquatic organisms.

Ishikawa, K., Asano, U., Nakamura, Y., Akasaki, K. (1976) Behavior and disappearance of benthic carb herbicide in water, soil and rice plant of paddy fields treated with its granular formulations. *Weed Res. Japan* 21: 16. (NC)

Kandasamy, D., Marimuthu, T., Rajukkannu, K., Raghuraj, R., Oblisami, G., Krishnamoorthy, K.K., Subrahmaniam, T.R. (1975) A study on the relationship between the dissipation of insecticides and rhizosphere microflora of paddy. *Madras Agric. J.* 62(4): 203–207.

*Summary:* A study on the interrelationship between the dissipation of two granular insecticides and different microbial populations in the rhizosphere soil of paddy corp indicated a positive correlation between the residues of phorate and actinomycete and *Azotobacter* populations. However, no such definite relationship could be recorded with carbofuran and various groups of microflora.

Keamey, P.C., Smith, R.J. Jr., Plimmer, J.R., Guardia, F.S. (1970) Propanil and TCAB residues in rice soils. *Weed Sci.* 18: 464–466.

*Summary:* We surveyed soils that produce rice (*Oryza sativa* L.) at the University of Arkansas Rice Branch Experiment Station at Stuttgart, Arkansas, to determine whether residues at 3,3',4,4'—tetrachloroazobenzene (hereinafter referred to as TCAB) accumulated with repeated applications of 3', 4' -dichloropropionanilide (propanil). We sampled Crowley silt loam with known histories of propanil application to determine the effect of depth, rate and time on TCAB formation. Propanil and TCAB were measured by electron capture gas chromatography. Low concentrations of TCAB (< 0.2 ppm) generally were detected in the surface 0 to 10.1-cm layer of soil receiving applications of propanil at rates of 6.7 kg/ha. Concentration and occurrence of TCAB decreased with increasing time and depth in soil.

Kirkpatrick, D., Biggs, S.R., Conway, B., Finn, C., Hawkins, D.R., Honda, T., Ishida, M., Powell, G.P. (1981) Metabolism of N-(2, 3-Dichlorophenyl)-3,4,5,6-tetrachlorophthalamic acid (Techlofthalam) in paddy soils and rice. *J. Agric. Food Chem.* 29: 1149–1153.

*Summary:* The metabolism of the bactericide N-(2, 3-dichlorophenyl)-3,4,5,6-tetrachlorophthalamic acid, techlofthalam, has been studied, under controlled conditions, in paddy soil and after application to rice plants by using the  $^{14}\text{C}$ -labeled compound. Reductive dechlorination of the tetrachlorophthalamic acid moiety was shown to be the major degradative pathway in paddy soil stored in laboratory flasks. Monodechlorinated products were detected after two weeks of incubation, and after thirty-two weeks more than 90 percent of the extractable radioactivity, equivalent to about 30 percent of the applied radioactivity, was associated with two or possibly more monodechlorinated products. Nine percent of the applied radioactivity was converted to  $^{14}\text{CO}_2$  during thirty-two weeks. The imide of techlofthalam was a minor metabolite in paddy soil but was the major transformation product detected in rice leaves treated with [ $^{14}\text{C}$ ] techlofthalam.

Kuwatsuka, S. (1973) Degradation products of sweep ad DCPA herbicides under flooded and upland conditions, in *Proc. Ann. Meet. Soc. Sci. Soil Manure, Japan* 19: 19. (NC)



Lee, H.K. (1981) Effect of rice straw amendment and repeated application of diazinon on the persistence of diazinon in submerged soils. *J. Korean Agric. Chem. Soc.* 24(1): 1-4. (NS)

*Notes:* Straw incorporation, which increases microbial activity and hastens the drop in redox potential in flooded soils, favors diazinon degradation.

Lichtenstein, E.P., Liang, T.T., Koeppe, M.K. (1983) Effect of soil mixing and flooding on the fate and metabolism of  $^{14}\text{C}$  Fonotos and  $^{14}\text{C}$  parathion in open and closed agricultural microcosm. *J. Econ. Entomol.* 76(2): 233-238.

*Notes:* One example of experimental design known as microcosm.

MacRae, I.C., Raghu, K., Bautista, E.M. (1969) Anaerobic degradation of the insecticide lindane by *Clostridium* sp. *Nature* (London) 221: 859. (NS)

MacRae, I.C., Raghu, K., Castro, T.F. (1967) Persistence and biodegradation of four common isomers of benzene hexachloride in submerged soils. *J. Agric. Food Chem.* 15: 911-914.

*Summary:* The persistence of the isomer of benzene hexachloride (lindane) when added to submerged tropical soils at a rate approximately three times that recommended for the protection of rice from stem borer infestation and of the alpha, beta and delta isomers of benzene hexachloride applied at similar rates was between seventy and ninety days. Losses of all four isomers from sterilized, flooded soil samples were much slower than from nonsterilized samples, indicating that the microflora of submerged soils is able to degrade benzene hexachloride. Microbial degradation of gamma-BHC was demonstrated by the release of  $\text{C}_{14}\text{O}_2$  from submerged soils treated with  $\text{C}_{14}$ -labeled-BHC. An application of gamma-BHC at a rate approximately five times the usual field rate apparently inhibited  $\text{CO}_2$  evolution from two tropical soils.

Mathur, S.P., Saha, J.G. (1975) Microbial degradation of lindane- $^{14}\text{C}$  in a flooded sandy loam soil. *Soil Sci.* 120: 301-307.

*Summary:* Lindane- $^{14}\text{C}$  degraded slowly (90 percent recovered) in a sandy loam soil, incubated for six weeks under flooded conditions. The degradation products were isolated and identified by gas chromatography and mass spectrometry. The major degradation product was -3,4,5,6-tetrachlorocyclohexane (> 5 percent), followed by -2,3,4,5,6-pentachlorocyclohex-1-ene (< 2 percent)

and small amounts of 1,2,4-trichlorobenzene, 1,2,3,5- and/or 1,2,4,5-tetrachlorobenzene, and 1,2,3,4-tetrachlorobenzene. Chlorophenolic metabolites of lindane, observed in plants, insects, and mammals were not detected in the soil.

Matsumura, F., Benezet, H.J. (1978) Microbial degradation of insecticides. Pages 623–667 in Hill, I.R., Wright, S.J.L. (eds.), *Pesticide Microbiology*. Academic Press, London. 844 pp. (NS)

*Notes:* A review with 133 references; ten references on submerged soils.

Matsumura, F., Krishna Murti, C.R. (1982) *Biodegradation of Pesticides*. Plenum Press, New York. 312 p.

*Notes:* A review with about 160 references; ten references on submerged soils.

Moon, Y.H., Kumatsuka, S. (1984) Properties and conditions of soils causing the dechlorination of the herbicide benthocarb in flooded soil. *J. Pest. Sci.* 9: 745–754.

*Notes:* Benthocarb is generally detoxified by hydrolysis, but its repeated application to flooded soil favoured the multiplication of anaerobic bacteria that decompose Benthocarb by reductive dechlorination, resulting in the formation of a very phytotoxic compound.

Mostafa, I.Y., El-Arab, A.E., Zayed, S.M.A.D. (1987) Fate of  $^{14}\text{C}$ -lindane in a rice-fish model ecosystem. *J. Environ. Sci. Health B* 22(2): 235–243.

*Summary:* A model ecosystem has been used to evaluate the impact of  $^{14}\text{C}$ -lindane on rice-fish agricultural system. The distribution of  $^{14}\text{C}$ -residues among the constituents of the model ecosystem was studied over a period of 90 days. The insecticide was found to be readily absorbed by the roots and translocated to all parts of the rice plant. The peak level in the shoots (26 ppm) and roots (105 ppm) of plants was reached to within three weeks. Lindane was concentrated in fish and residues as high as 90 ppm could be detected after thirty days. The major part of the residues present in the different constituents of the ecosystem could be extracted with hexane and proved to contain solely the parent compound. The data obtained show that lindane possesses a relatively low biodegradability in fish and in rice plant. The insecticide accumulates in fish and rice plant to considerable extent.

Murthy, N.B.K., Kaufman, D.D. (1978) Degradation of pentachloronitrobenzene (PCNB) in anaerobic soils. *J. Agric. Food. Chem.* 26: 1151–1156.(NC)

Murthy, N.B.K., Kaufman, D.D., Fries, G.F. (1979) Degradation of pentachlorophenol (PCP) in aerobic and anaerobic soil. *J. Environ. Sci. Health* 14 B: 1–14.

*Summary:* Aerobic and anaerobic degradation of  $^{14}\text{C}$ -labeled pentachlorophenol (PCP) was examined in nitrogen aerated, moist Hagerstown silty clay loam with or without cellulose amendments. In anaerobic soil, PCP reduced soil respiration in the presence of cellulose; volatilization losses accounted for only 0.5 percent of the PCP added to soil; no  $^{14}\text{CO}_2$  was detected; and organic solvent extractable radioactivity was the same from all treatments. Gas and thin-layer chromatographic analysis of the soil extracts showed the presence of pentachloroanisole in both aerobic and anaerobic soils. 2,3,5,6- and 2,3,4,5-tetrachlorophenols and 2,3,6-trichlorophenol were also detected as degradation products by chromatography after methylation. Further degradation of the pentachloroanisole was examined in both aerobic and anaerobic soils.

Nakamura, Y., Ishikawa, K., Kuwatsuka, S. (1977) Degradation of benthicarb in soils as affected by soil conditions. *J. Pest. Sci.* 2: 7–16.

*Summary:* Some factors affecting the degradation of  $^{14}\text{C}$ -benthicarb (S-4-chlorobenzyl N,N-diethylthiocarbamate) labeled at the benzene-ring in soils were studied. The degradation rates of  $^{14}\text{C}$ -benthicarb in three different soils under upland, oxidative flooded, and reductive flooded conditions were compared.  $^{14}\text{C}$ -Benthicarb was rapidly degraded under oxidative conditions, but slowly under reductive conditions. Very small differences in the degradation rates were observed among different soils. Under oxidative conditions  $^{14}\text{C}$ -carbon dioxide was liberated remarkably with the degradation of  $^{14}\text{C}$ -benthicarb. The degradation was remarkably retarded by sterilizing the soils. The repeated application of benthicarb, or its incorporation into the soil with simetryne, CNP or propanil had no significant effect on the degradation rate.

Ohisa, N., Yamaguchi, M. (1978a) Degradation of gamma-BHC in flooded soils enriched with peptone. *Agric. Biol. Chem.* 42: 1983. (NC)

*Notes:* The enrichment of soil populations of *Clostridium rectum*, a bacterium that degrades BHC by a cometabolic process, was not caused by BHC application but by peptone addition.

Ohisa, N., Yamaguchi, M. (1978b) Gamma-BHC degradation accompanied by the growth of *Clostridium rectum* isolated from paddy field soil. *Agric. Biol. Chem.* 42: 1819–1823.

*Summary:* A BHC decomposer isolated from a ricefield soil was identified as *Clostridium rectum*. The most dominant degradation intermediate from gamma-BHC was identified to be remarkably reduced in the resting state, e.g., spore-formed cell or washed cell suspension. The growth and the BHC decomposing ability of *C. rectum* were inhibited simultaneously by oxygen, chloramphenicol, streptomycin, and pentachlorophenol. BHC degradation is discussed in relation to the cometabolism.

Parr, J.E., Smith, S. (1973) Degradation of trifluralin laboratory conditions and soil anaerobiosis. *Soil Sci.* 115: 55–63.

*Summary:* The rate and extent of photodecomposition of trifluralin in n-hexane solutions exposed to laboratory light were concentration-dependent. Trifluralin degraded very slowly in either the dark or light at a concentration of 200 ppm. However, rapid decomposition occurred at concentrations of 1.0 and 0.1 ppm in the light, but a considerably slower rate in the dark. Trifluralin degrades in soil by two principal pathways, the aerobic pathway involving sequential dealkylation of propyl groups, and the anaerobic pathway involving initial reduction of the nitro groups. Ultimately, polar products are probably formed during the latter stage of degradation. Degradation of trifluralin was more rapid and extensive in substrate-amended soil under anaerobic ( $N_2$ ) conditions compared with well-aerated ( $CO_2$ -free air) systems, and followed the order of moist (1/3 bar) anaerobic > flooded anaerobic > moist aerobic. Degradation in these environments after 20 days was 99, 45, and 15 percent, respectively. More trifluralin volatilized from the moist aerobic soil compared with moist anaerobic systems because degradation was more extensive in the latter environment. Volatilization was effectively retarded in the flooded anaerobic environment. Evidence for microbiological involvement in the initial degradation of trifluralin under soil anaerobiosis was obtained, including (1) enhanced degradation in the presence of an organic substrate, (2) lack of trifluralin degradation in moist anaerobic environments after autoclaving, (3) resumption of respiratory activity in autoclaved systems after reinoculation, which corresponded with increased degradative activity, and (4) a temporary lag period or suppression of respiratory activity and trifluralin degradation from the presence of  $KN_3$  as a biological inhibitor, with simultaneous resumption of respiration and degradation soon after chemical dissipation of  $KN_3$ .

Parr, J.F., Smith, S. (1974) Degradation of DDT in an everglades muck as affected by lime, ferrous ion and anaerobiosis. *Soil Sci.* 118: 45–52.

*Notes:* Liming flooded/anaerobic acid soils was reported to cause a rapid conversion of DDT to DDE.

Parr, J.F., Smith, S. (1976) Degradation of toxaphene in selected anaerobic soil environments. *Soil Sci.* 121: 52-57. (NC)

*Notes:* A low or negative redox potential favored the degradation of Toxaphene.

Pathak, M.C., Encarnacion, D., Dupo, H. (1974) Application of insecticides in the root zone of rice plants. *Indian J. of Plant Protection* 1(2): 1-16.

*Notes:* A better efficiency of several insecticides when placed in the vicinity of the root was demonstrated indicating that application could be reduced as compared with floodwater application.

Pinhero, R.G., George, T.U., Tomy, P.J. (1988) Residual toxicity of granular insecticides to fishes and prawns in the pokkali fields. *Agric. Res. Kerala* 26(2): 263-265.

*Summary:* Among the granular insecticide tested, none of the insecticides was found to be completely safe for use in pokkali fields.

Raghu, K., MacRae, I.C. (1966) Biodegradation of the gamma isomer of benzene hexachloride in submerged soils. *Science* 154: 263-364.

*Summary* Determination of the residual gamma isomer of benzene hexachloride (gamma-BHC) by gas chromatography showed that the insecticide persisted longer in sterilized flooded soils than in nonsterilized flooded soils. A second addition of gamma-BHC to one of the nonsterilized soils (fifty-five days after the first application) disappeared more rapidly than the first addition. These results strongly indicate biodegradation of gamma-BHC in flooded soils.

*Notes:* Half-life in nonsterilized soil was about eighteen days at the first application and twelve days at the second application.

Rajagopal, B.S., Brahmaprakash, G.P., Sethunathan, N. (1983) Degradation of carbofuran by enrichment cultures and pure cultures of bacteria from flooded soils. *Rice Res. News.* 4(1-2), CRRI. ICAR, India. (NS)

*Notes:* Enrichment cultures from soil repeatedly treated with pesticide have been used to isolate carbofuran degrading bacteria but even enrichment cultures showed a lag in the degradation of carbofuran.

Rajagopal, B.S., Brahmaprakash, G.P., Sethunathan, N. (1984) Degradation of carbofuran by enrichment cultures and pure cultures of bacteria from flooded soils. *Environ. Pollut.* (Series A) 36: 61-73.

*Notes:* Test tube experiment showing a built-up of the microflora degrading carbofuran by comparing inocula origination from fields previously treated with carbofuran with inocula originating from non-treated fields.

Rajagopal, B.S., Chendrayan, K., Reddy, B.R., Sethunathan, N. (1983) Persistence of carbaryl in flooded soils and its degradation by soil enrichment cultures. *Plant Soil* 73: 35–45.

*Notes:* The addition of ammonium nitrogen to a mineral medium retarded the degradation of the nitrogenous pesticide carbaryl by soil enrichment cultures.

Rajagopal, B.S., Rao, V.R., Najendrappa, G., Sethunathan, N. (1984) Metabolism of carbaryl and carbofuran by soil enrichment and bacterial cultures. *Can. J. Microbiol.* 30: 1458–1466.

*Notes:* Test tube experiment with 20 g soil showing a shift in dominant microbial populations when carbaryl (*Bacillus* dominant) was replaced with carbofuran (*Arthrobacter* dominant). Degradation steps are described.

Rajagopal, B.S., Sethunathan, N. (1984) Influence of nitrogen fertilizers on the persistence of carbaryl and carbofuran in flooded soils. *Pest. Sci.* 15: 591–599.

*Summary:* Ammonium sulphate and urea but not potassium sulphate, increased the persistence of carbaryl in a flooded laterite soil with a low nitrogen content (0.04 percent), but not in an alluvial soil with a higher nitrogen content (0.11 percent). Consequently, after forty days, more than 50 percent of the  $^{14}\text{C}$  in a  $^{14}\text{C}$  carbaryl and  $^{14}\text{C}$  carbofuran remained in the soils as hydrolysis product plus soil bound residues.

*Notes:* Test tube experiment with 20 g soil.

Rajaram, K.P., Rao, Y.R., Sethunathan, N. (1978) Inhibition of biological hydrolysis of parathion in rice straw-amended flooded soil and its reversal by nitrogen compounds and aerobic conditions. *Pest. Sci.* 9: 155–160.

*Summary:* The effect of nitrogen compounds and moisture regimes on the inhibition of the biological hydrolysis of parathion in rice straw-amended soil under flooded conditions was studied. Single applications of rice straw, potassium nitrate or ammonium sulphate to the flooded soil, inoculated with parathion-hydrolysing enrichment culture, inhibited the hydrolysis of the insecticide; the inhibition was reversed, however, in combined applications of rice straw with potassium nitrate or with ammonium sulphate. Aqueous extracts of rice straw-amended soils incubated under flooded undisturbed conditions as well as at 100

percent moisture inhibited the hydrolysis. The inhibitory factor was not formed in rice straw-amended flooded soils incubated at 50 and 75 percent moisture levels.

Rajaram, K.P., Sethunathan, N. (1975a) Effect of organic sources on the degradation of parathion in flooded alluvial soil. *Soil Sci.* 119: 296–300.(NC)

Rajaram, K.P., Sethunathan, N. (1975b) Persistence and biodegradation of hinosan in soil. *Bull. Environ. Contam. Toxicol.* 16: 709–715.(NC)

*Notes:* Comparison of persistence under upland and flooded conditions. Cited from Sethunathan and Siddaramappa (1978).

Rajasekhar Reddy, B., Sethunathan, N. (1983a) Mineralization of parathion in the rice rhizosphere. *Appl. Environ Microbiol.* 45(3): 826–829.

*Notes:*  $^{14}\text{CO}_2$  evolution from ring labelled parathion was studied in the rhizosphere of rice seedlings. Results suggest that soil planted with rice permits significant ring cleavage, especially under flooded conditions. 5.5 percent of  $^{14}\text{C}$  was evolved as  $^{14}\text{CO}_2$  in unplanted nonflooded soil whereas 22.6 percent was evolved in planted and flooded soil.

Rajasekhar Reddy, B., Sethunathan, N. (1983b) Mineralization of parathion in the rhizosphere of rice and pearl millet. *J. Agric. Food Chem.* 31: 1379–1381.

*Notes:* Mineralization of Parathion in the rhizosphere of rice was more pronounced at the seedling stage than at the maximum tillering and panicle initiation stage. The degree of rhizosphere effect also depended on the rice variety. The rhizosphere effect was related to the root oxydase activity in rice but not necessarily to the biomass of the plant. Pearl millet, a C4 plant, exerted a more pronounced rhizosphere effect on ring clivage of parathion than rice, a C3 plant.

Rao, A.V., Sethunathan, N. (1974) Degradation of parathion by *Penicillium waksmani* Zaleski isolated from flooded acid sulphate soil. *Arch. Microbiol.* 97: 203–208. (NC)

Rao, Y.R., Sethunathan, N. (1979) Effect of ferrous sulfate on the degradation of parathion in flooded soil. *J. Environ. Sci. Health* 14B: 335. (NC)

Read, D.C. (1987) Greatly accelerated microbial degradation of aldicarb in re-treated field soil, in flooded soil, and in water. *J. Econ. Entomol.* 80: 156–163.

*Summary:* The successive application of aldicarb as sub-surface band-in-row soil treatment at 4 kg ai in the same field resulted in development of strains of microorganisms that rapidly broke down aldicarb in acid mineral soils of pH above ca. 6. Rate of accelerated microbial degradation depended on pH and moisture content of the soil, amount applied per treatment, number of treatments, and time period between treatments.

Ross, L.J., Sava, R.J. (1986) Fate of thiobencarb and molinate in ricefields. *J. Environ. Qual.* 15(3): 220–225.

*Summary:* The fate of thiobencarb (S-[4-chlorobenzyl] N, N-diethyl-thiolcarbamate) and molinate (S-ethyl hexahydro-1 H-azepine-1-carbothioate) in air, water, soil, and vegetation of rice (*Oryza sativa* L.) fields was documented for thirty-two days following application. Analysis of variance was used to determine if holding periods facilitated herbicide dissipation in water prior to release to drainage canals. Maximum thiobencarb concentrations in air, water, soil, and vegetation were 1.4 µg/cum, 576 µg/L, 3,860 µg/kg, and 1,750 µg/kg, respectively. During the six-day holding period, thiobencarb concentrations in water did not decline significantly, indicating that this period was not sufficient to facilitate dissipation. The mass balance budget indicated that thiobencarb was predominantly distributed between water (34 percent) and soil (43 percent) and < 1 percent was located in air and vegetation. Maximum molinate concentrations in air, water, soil, and vegetation were 48 g/m<sup>3</sup>, 3,430 g/li, 2,210 g/kg, and 918 g/kg, respectively. Molinate concentrations in water declined significantly during the holding period, indicating that this water management practice facilitated dissipation of molinate. The mass balance budget indicated that as much 81 percent of the molinate applied was dissolved in water followed by soil (10 percent), air (9 percent), and vegetation (< 1 percent). Partitioning of these herbicides in the field was closely related to their physicochemical properties.

Seiber, J.N., Heinrichs, E.A., Aquino, G.B., Valencia, S.L., Andrade, P., Argente, A.M. (1978) *Residues of carbofuran applied as a systemic insecticide in irrigated wetland rice: Implications for insect control*. IRPS no 17, 28 pp., International Rice Research Institute, Manila, Philippines.

*Notes:* Persistence of pesticides depends on the method of application. Carbofuran placed in gelatin capsules in the root zone persisted for about sixty days. Soil incorporation provided a persistence of about sixty days. A much faster dissipation was observed when seedling roots were soaked in carbofuran solution.



Seiber, J.N., McChesney, M.M., Sanders, P.F., Woodrow, J.E. (1986) Models for assessing the volatilization of herbicides applied to flooded ricefields. *Chemosphere* 15(2): 127–138.

*Summary:* Volatilization rates of MCPA, thiobencarb, and molinate from water were calculated using the EXAMS aquatic fate computer model, and measured in a laboratory chamber and in flooded ricefields. A fair to good correlation was obtained between EXAMS-calculated and chamber measured rates for all three herbicides. Field-measured values correlated well with chamber measured rates for thiobencarb and molinate. For MCPA, field-measured values were much higher than expected for volatilization from water alone. In this case, the presence of plant and other surface residues in the field made the major contribution to observed volatilization. For MCPA, 4-chloro-o-cresol flux was comparable to that of the parent herbicide.

Sethunathan, N. (1971) Biodegradation of diazinon in paddy fields as a cause of its inefficiency for controlling brown planthoppers in ricefields. *PANS* 17(1): 18–19. (NS)

Sethunathan, N. (1972) Diazinon degradation in submerged soil and rice-paddy water. *Adv. Chem. Ser.* 111: 244–255.

*Summary:* Diazinon persisted for about fifteen days in a flooded soil (pH 6.6) that had been treated previously with the insecticide; but in a flooded soil that had never been exposed to diazinon, it persisted for about sixty days. Similarly, water from a diazinon-treated ricefield inactivated the insecticide within five days after incubation. Microorganisms that developed in response to insecticide application accelerated its hydrolysis and subsequent mineralization of the hydrolysis product, 2-isopropyl-6-methyl-4-hydroxy pyrimidine, to CO<sub>2</sub>. A *Flavobacterium* sp., isolated from water of a treated ricefield, had exceptionally high capability to metabolize diazinon as sole carbon source. This provides unequivocal evidence that microbes are involved in the rapid inactivation of diazinon in ricefields.

Sethunathan, N. (1973a) Degradation of parathion in flooded acid soils. *J. Agric. Food Chem.* 21: 602–604.

*Notes:* In the acid rice soils in Kerala, India, Parathion degraded faster in the soil that had a higher organic matter content.

Sethunathan, N. (1973b) Microbial degradation of insecticides in flooded soil and in anaerobic cultures. *Res. Rev.* 47: 143–165.

*Notes:* A review with sixty-three references.

Sethunathan, N. (1973c) Organic matter and parathion degradation in flooded soil. *Soil Biol. Biochem.* 5: 641–644.

*Summary:* The effect of rice straw on parathion degradation in a flooded alluvial soils was investigated. In soils inoculated with an enrichment culture which exhibited an exceptionally high ability to hydrolyze parathion, rice straw amendments inhibited parathion hydrolysis to p-nitrophenol and diethyl thiophosphoric acid. On the other hand, in uninoculated soils amended with rice straw, aminoparathion and an unidentified metabolite evidently possessing a P = S bond were detected. Thus, the influence of organic matter on the persistence of parathion in flooded soil is governed by the metabolic pathway involved in the degradation.

Sethunathan, N. (1984a) Biodegradation of pesticides in tropical rice ecosystem. Paper presented at the Ecotoxicology Project Meeting (SCOPE) held at Brussels Belgium, July 5-6, 1984. 34 pp. (NC)

Sethunathan, N. (1984b) *Pesticide degradation in tropical rice soil environment*. Project report. 56 pp. CRRI, Cuttack, India. (NC)

*Notes:* A technical report to the Department of Environment of India. Reported results were then published in scientific journals.

Sethunathan, N., Adhya, T.K., Raghu, K. (1982) Microbial degradation of pesticides in tropical soils. Pages 91–115 in Matsumura, F., Krishna Murty, C.R. (eds.), *Biodegradation of Pesticides*. (NS)

*Notes:* A review with 98 references.

Sethunathan, N., Bautista, E.M., Yoshida, T. (1969) Degradation of benzene hexachloride by a soil bacterium. *Can. J. Microbiol.* 15: 1349–1354.

*Summary:* Attempts to characterize the breakdown product formed during the anaerobic degradation of the gamma isomer of benzene hexachloride (gamma-BHC,  $C_6H_6Cl_6$ ) by the *Clostridium* sp. were made. Analysis by gas chromatography and thin-layer chromatography indicated that the degradation product of gamma-BHC and alpha-BHC differed from gamma-pentachlorocyclohexene ( $C_6H_5Cl_5$ ), a direct product of dehydrochlorination of gamma-BHC. The ability of the bacterium to convert DDT to DDD by reductive dechlorination suggested that a similar mechanism might degrade gamma-BHC to gamma-pentachlo-

rocylohexane ( $C_6H_7C_{15}$ ). Potassium nitrate inhibited the bacterial degradation of gamma-BHC whereas potassium sulfate and potassium chloride enhanced it.

Sethunathan, N., MacRae, I.C. (1969) Persistence and biodegradation of diazinon in submerged soils. *J. Agric. Food Chem.* 17: 221–225.

*Summary:* Only 2 to 6 percent of the originally applied diazinon [0,0-diethyl 0-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate] remained in the soils between 50 and 70 days after application when added to three submerged tropical soils at a rate about seven times that recommended for protecting rice plants from stem borer infestation and certain virus-transmitting leaf hoppers. Losses of the insecticide from sterilized samples of two of the soils were much slower than from nonsterilized samples, indicating microbial participation in diazinon degradation in these two soils. Diazinon disappeared rapidly in sterilized samples of the third soil, an acid clay of pH 4.7, apparently because of its instability under acid conditions. Microbial degradation of the pyrimidine ring of the diazinon labeled at the two positions of the pyrimidine ring. *Streptomyces* sp. isolated from diazinon-treated submerged soil could degrade diazinon in shake cultures, but only in the presence of glucose. Diazinon at 2–20 kg/ha caused a large increase in populations of actinomycetes.

Sethunathan, N., Pathak, M.D. (1971) Development of diazinon-degrading bacterium in paddy water after repeated applications of diazinon. *Can. J. Microbiol.* 17: 699–702.

*Summary:* A decline in the brown planthopper control effectivity of diazinon was noticed after its continuous application to rice paddies for three one or two years at the International Rice Research Institute. In a study undertaken to determine the factor involved in this decline, rapid inactivation of diazinon was recorded within three to five days of its incubation with water from ricefield that had received several applications of diazinon. During the same period, its degradation in water from an untreated ricefield was non-significant. This indicated the development of a degrading agent in paddy water following diazinon treatments. The inactivation of diazinon on incubation with water from treated fields was retarded if the incubation mixture was sterilized or kept anaerobically. Release of  $^{14}CO_2$  from  $^{14}C$ -diazinon was rapid from water of treated fields, but was inhibited when streptomycin was added to the system. A lag of two or three days, followed by a rapid degradation, was generally evident. Thus these data established the fact that aerobic biological agents, capable of degrading diazinon in paddy water, develop after diazinon application. A bacterium, *Arthrobacter* sp., capable of metabolizing diazinon in the presence of ethyl alcohol or glucose was isolated from paddy water of treated fields.

Sethunathan, N., Pathak, M.D. (1972) Increased biological hydrolysis of diazinon after repeated application in rice paddies. *J. Agric. Food Chem.* 20(3): 586–589.

*Notes:* Repeated application of diazinon caused a rapid degradation which was of microbial nature. The addition of streptomycin to the incubation mixture prevented breakdown of diazinon.

Sethunathan, N., Rajaram, K.P., Siddaramappa, R. (1975) Persistence and microbial degradation of parathion in Indian rice soils under flooded conditions. In *Origin and fate of chemical residues in food*, Agriculture and Fisheries Communication 1.2: 9–18, International Atomic Energy Agency, Vienna Austria.

*Notes:* Presents data on (1) the effects of repeated application and native and applied organic matter on parathion degradation, and (2) bacterial degradation of Lindane.

Sethunathan, N., Ramakrishna, C., Bank, S., Venkateswarlu, K., Raghu, K. (1978) Microbial degradation of pesticides in tropical soils: A review of work in India. Pages 471–481 in Edwards, C.A., Veeresh, G.K., Krueger, H.R. (eds.), *Pesticide residues in the environment in India*. FAO/UNESCO/UNDP/ICAR/UAS pub. 524 pp. (NS)

*Notes:* A review with 32 references.

Sethunathan, N., Siddaramappa, R. (1978) Microbial degradation of pesticides in rice soils. Pages 479–497 in *Soils and Rice*. IRRI, Manila, Philippines.

*Notes:* A review with 93 references.

Sethunathan, N., Siddaramappa, R., Siddarama Gowda, T.K., Rajaram, K.P., Barik, S., Rao, V.R. (1976) Pesticide-soil microflora interactions in flooded rice soils. Pages 27–36 in *Trace contaminants of agriculture, fisheries and food in developing countries*. Pesticide-Soil Microflora.

*Summary:* Isotope studies revealed that gamma and beta isomers of HCH (hexachlorocyclohexane) decomposed rapidly in nonsterile soils capable of attaining redox potentials of –40 to –100 mV within 20 days after flooding. Degradation was slow, however, in soils low in organic matter and in soils with extremely low pH and positive potentials, even after several weeks of flooding. Under flooded conditions, endrin decomposed to six metabolites in most soils. There is evidence that biological hydrolysis of parathion is more widespread than hitherto believed, particularly under flooded soils conditions. Applications

of benomyl (fungicide) to a simulated-oxidized zone of flooded soils favoured nitrification.

Sethunathan, N., Sudhakar-Barik, Venkateswarlu, K., Wahid, P.A., Ramakrishna, C., Pal, S.S., Ray, R.C., Chendrayan, K., Rao, Y.R., Rao, V.R., Adhya, T.K. (1980) Effect of combined pesticides application on their persistence in flooded rice soils. Pages 259–281 in *Agrochemical-biota interactions in soil and aquatic ecosystems*. Panel proceedings series, I.A.E.A. Vienna.

*Summary:* Pesticide-microflora interactions were studied with special reference to flooded soils. The principal metabolic pathway for the insecticide parathion shifted from nitro group reduction to hydrolysis upon the repeated additions of parathion or its hydrolysis product, p-nitrophenol, to a flooded soil. Both nitro group reduction and hydrolysis are cometabolic reactions; the tremendous build-up of parathion-hydrolysing micro-organisms after parathion additions occurred at the expense of the product of the primary cometabolic hydrolysis, p-nitrophenol. The fungicide benomyl significantly increased the persistence of generally short-lived parathion in flooded soil by inhibiting nitro group reduction and hydrolysis. Benomyl inhibited nitrification, iron reduction and drop in the redox potential in a flooded soil. Aerobically incubated flooded soil liberated more  $^{14}\text{CO}_2$  from the  $^{14}\text{C}$  in p-nitrophenol than anaerobically incubated flooded soil. The lag of about twenty days in the degradation of carbofuran and its high water solubility may raise problems of carbofuran residues in the run-off waters from carbofuran-treated ricefields, particularly in areas comprised of soils capable of remaining acidic even under flooded conditions. Interestingly, during forty-day flooding,  $^{14}\text{CO}_2$  evolution from Mg- $^{14}\text{C}$ -carbofuran was virtually negligible whereas 16–27 percent of carbonyl- $^{14}\text{C}$  was converted to  $^{14}\text{CO}_2$ . Evidence suggests that redox potential, reducing capacity and certain reduction reactions, assayed for example in terms of nitrate disappeared or reduced iron formed, could be used as simple and suitable indicators of the pesticide-degrading capacity of anaerobic systems. Dehydrogenase activity is well pronounced in predominantly anaerobic flooded soil and may have the obvious advantage over the  $^{14}\text{CO}_2$  evolution technique as an assay for the pesticide-degrading capacity of anaerobic systems.

Sethunathan, N., Yoshida, T. (1973a) A *Flavobacterium* sp. that degrades diazinon and parathion. *Can. J. Microbiol.* 19: 973–975.

*Summary:* A *Flavobacterium* sp., isolated from paddy water by enrichment culture technique, decomposed diazinon in a mineral medium as sole carbon source. The bacterium readily hydrolyzed diazinon to 2-isopropyl-6-methyl-4-hydroxy-pyrimidine which was then converted to carbon dioxide. The bacterium

also converted parathion to p-nitrophenol. The enzyme involved in the hydrolysis was constitutive.

Sethunathan, N., Yoshida, T. (1973b) Degradation of chlorinated hydrocarbons by *Clostridium* sp. isolated from lindane-amended flooded soil. *Plant Soil* 38: 663-666.

*Summary:* A *Clostridium* sp., isolated from flooded soil amended with lindane (-BHC), decomposed methoxychlor, -BHC and hetachlor in that order under anaerobic condition. During the bacterial degradation of ring-labeled  $^{14}\text{C}$ -BHC there was a net loss of radioactivity from the reaction mixture. Release of  $^{14}\text{CO}_2$  during the degradation of  $^{14}\text{C}$ -BHC was negligible. Methane was not detected as an end product of -BHC breakdown.

Sethunathan, N., Yoshida, T. (1973c) Parathion degradation in submerged rice soils in the Philippines. *J. Agric. Food Chem.* 21: 504-506.

*Summary:* The persistence of parathion (0,0-diethyl 0-p-nitrophenyl phosphorothioate) in four Philippine rice soils was investigated in submerged and upland conditions. The parathion in the soils after incubation at 300 was extracted with a hexaneacetone mixture and the amount was determined by gas chromatography. The insecticide disappeared more rapidly from submerged soils than from upland soils. In submerged soils parathion was reduced to aminoparathion (0,0-diethyl 0-p-aminophenyl phosphorothiate). Autoclaving of the soils increased the persistence of parathion under submerged conditions, indicating microbial participation in its degradation. Parathion degraded faster in flooded soil inoculated with parathion-hydrolyzing *Flavobacterium* sp. than in uninoculated soil.

Siddaramappa, R. (1975) Biodegradation of insecticides in rice soils. Ph.D. thesis (Agricultural chemistry), Orissa University of Agricultural and Technology, Bhubaneswar, CRRRI Cuttack. 127 pp.

*Notes:* A study of the degradation of parathion and its related nitrophenols and BHC in soils and by microorganisms.

Siddaramappa, R. (1978) *Fate of carbofuran in flooded soil and in rice plants*. A terminal report submitted to the International Rice Research Institute, Los Baños, Philippines. December 3, 1976-November 29, 1978. 65 pp. (NS)

Siddaramappa, R., Rajaram, K.P., Sethunathan, N. (1973) Degradation of parathion by bacteria isolated from flooded soil. *Appl. Microbial.* 26: 846-849.

*Summary:* Two bacteria, *Bacillus* sp. and *Pseudomonas* sp., were isolated from parathion-amended flooded alluvial soil which exhibited parathion-hydrolyzing ability. *Bacillus* sp. readily liberated nitrite from the hydrolysis product, p-nitrophenol, but not from intact parathion. *Pseudomonas* sp. hydrolyzed parathion and then released nitrite from p-nitrophenol. These studies establish bacterial degradation of parathion past the p-nitrophenol stage to the end product, nitrite.

Siddaramappa, R., Seiber, J.M. (1979) Persistence of carbofuran in flooded rice soils and water. *Prog. Water Technol.* 11: 103–111.

*Summary:* The persistence of carbofuran (2,3-dihydro-2,2 dimethyl-7-benzofuranyl methyl carbamate) in soil and water samples collected from different rice growing areas in the Philippines was studied under laboratory conditions. After extraction, carbofuran was estimated by gas-liquid chromatography. Beside, studies with  $^{14}\text{C}$ -labelled carbofuran were also conducted in some experiments. Rapid degradation of carbofuran occurred in two out of three sets of irrigation and paddy water samples. Degradation of carbofuran in water was mainly by non-biological process(es); but in soil, it was associated with microbial activities as well. The rate of degradation of carbofuran in water was related to the initial pH and that repeated application to paddy water did not result in a “build-up effect”. Application carbofuran to a depth of about 3 cm from the surface of flooded soil reduced the concentrations in standing water but increased the persistence in soil significantly. Furthermore, addition of various nitrogenous fertilizers such as ammonium sulfate or urea along with carbofuran influenced the duration of the insecticide’s activity in soil and water.

Siddaramappa, R., Sethunathan, N. (1975) Persistence of gamma-BHC and beta-BHC in Indian rice soils under flooded conditions. *Pest. Sci.* 6: 395–403. (NS)

Siddaramappa, R., Sethunathan, N. (1976) Volatilization of lindane from water in soil-free and flooded soil systems. *J. Environ. Sci. Health* 11B. 119. (NC)

Siddaramappa, R., Tirol, A., Watanabe, I. (1979) Persistence in soil and absorption and movement of carbofuran in rice plants. *J. Pest. Sci.* 4: 473–479.

*Summary:* The persistence of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methyl carbamate) applied to paddy water or the root zone of flooded soil and its influence on absorption and translocation in rice plants were studied under greenhouse conditions. Also the degradation of carbofuran as affected by soil types and the effect of repeated root zone treatments was investigated under laboratory conditions without rice plants by gas-liquid chromatography, thin-layer chromatography, and the isotape technique. Placement of

carbofuran at the root zone of rice resulted in a significant increase in persistence in soil as compared with paddy water application. The absorption and translocation rates of carbofuran in rice plants were more rapid in paddy water application, however, while in the root zone placement those rates increased gradually. Most of the carbofuran absorbed by rice accumulated in the leaves, particularly, the tip portions. A consistently lower concentration was present in the stem portion of the plant. Microbial degradation of carbofuran in three soils was studied; degradation was slowest in soil with the lowest pH.

Siddaramappa, R., Tirol, A.C., Seiber, J.N., Heinrich, E.A., Watanabe, I. (1978) The degradation of carbofuran in paddy water and flooded soil of untreated and retreated ricefields. *J. Environ. Sci. Health* 13B: 369-380.

*Summary:* Loss of carbofuran from paddy water and in flooded soil was studied in the laboratory and under field conditions. Carbofuran was rapidly hydrolyzed to carbofuran phenol in just five days after its application to paddy water. Hydrolysis of carbofuran appeared to be primarily due to chemical, but degradation of carbofuran phenol was biological. Previous applications of carbofuran to paddy water had no appreciable effect on the rate of degradation of the insecticide. However, in soil from the carbofuran-treated plot, a more rapid degradation of carbofuran occurred only after three weeks of incubation under laboratory conditions. Incubating paddy water under light or dark conditions revealed that photo-decomposition of carbofuran may not be occurring. The data furnished no evidence that microbial acclimatization plays a major role in the dissipation of carbofuran applied as granules to paddy water.

Siddaramappa, R., Tirol, A.C., Watanabe, I. (1977) Fate of carbofuran under flooded soil conditions. IRRI Saturday Seminar, October 8, 1977. 17 pp. (NS)

Siddaramappa, R., Watanabe, I. (1978) Fate of carbofuran in flooded soil and in rice plants. *International Rice Research Newsl.* 3(6): 15. (NS)

*Notes:* The authors conclude that the rice plant may lose appreciable quantities of carbofuran through vaporization.

Siddaramappa, R., Watanabe, I. (1979) Evidence for vapor loss of  $^{14}\text{C}$ -carbofuran from rice plants. *Bull. Environ. Contam. Toxicol.* 23: 544-551. (NS)

*Notes:* The authors conclude that the rice plant may lose appreciable quantities of carbofuran through vaporization.

Soderquist, C.J., Bowers, J.B., Crosby, D.G. (1977) Dissipation of molinate in a ricefield. *J. Agric. Food Chem.* 25(4): 940-945.



*Summary:* The dissipation of the herbicide molinate (S-ethyl hexahydro-1H-azepine-1-carbothioate) in a California ricefield was investigated. Laboratory experiments indicated that while dilute aqueous solutions of molinate were stable in sunlight, irradiations in the presence of tryptophan resulted in decomposition primarily to 1 [(ethylsulfinyl)carbonyl]hexahydro-1H-azepine, S-ethyl hexahydro-2-oxo-1H-azepine-1-carbothioate, and hexamethyleneimine. Analysis for molinate and its degradation products at sub-ppm levels in water, soil, and air samples collected from a commercially treated field, together with laboratory studies, showed that volatilization of molinate from water was the primary mode of dissipation, although photodecomposition products were present in field water.

Soderquist, C.J., Crosby, D.G. (1975) Dissipation of 4-Chloro-2-methylphenoxyacetic acid (MCPA) in a ricefield. *Pestic. Sci.* 6: 17–33. (NC)

Sudhakar-Barik, Wahid, P.A., Ramakrishna, C., Sethunathan, N. (1979) A change in the degradation pathway of parathion after repeated application to flooded soil. *J. Agric. Food. Chem.* 27: 1391–1392.

*Summary:* The degradation pathway of parathion shifted to hydrolysis from reduction after repeated applications of parathion or its hydrolysis product, p-nitrophenol, to a flooded soil. This shift occurred as a result of the proliferation of parathion-hydrolyzing microorganisms that utilized p-nitrophenol as the energy source. This is probably the first report of the enrichment of a population capable of degrading a parent molecule upon application of the primary product of its metabolism.

Sudhakar-Barik, Sethunathan, N. (1978a) Biological hydrolysis of parathion in natural ecosystems. *J. Environ. Qual.* 7: 346–348. (NC)

Sudhakar-Barik, Sethunathan, N. (1978b) Metabolism of nitrophenols in flooded soils. *J. Environ. Qual.* 7: 349–352.

*Summary:* Nitrophenols (p-, o-, and m-isomers and 2,4-dinitrophenol) disappeared fairly rapidly from flooded alluvial and organic matter-rice acid sulfate (pokkali) soils inoculated with parathion (0,0-diethyl 0,p-nitrophenyl phosphorothioate)-enrichment cultures from the respective soils. Nitrite, one of the reported end-products of nitrophenol (0,0-dimethyl 0,p-nitrophenyl phosphorothioate) metabolism, accumulated only in inoculated alluvial soil, irrespective of the type of nitrophenol added. In an isotope study, ring cleavage of p-nitrophenol leading to carbon dioxide was demonstrated in flooded soils inoculated with parathion-enrichment culture, particularly under stirred conditions.

Nitrophenols decomposed also in uninoculated samples of both soil types, though slowly as compared to inoculated soils; but nitrite and carbon dioxide were not formed. Resting cells of a bacterium, *Pseudomonas* sp. ATCC 29353, readily hydrolyzed parathion and then liberated nitrite from p-nitrophenol. In cell-free suspension, the reaction ceased at the p-nitrophenol stage. In bacterial cultures, parathion was hydrolyzed without proliferation while subsequent degradation of p-nitrophenol involved metabolism leading to bacterial enrichment.

Sudhakar-Barik, Sethunathan, N. (1979) Persistence of parathion increased by benomyl in flooded soil. *Prog. Water Technol.* 11: 113–119.

*Summary:* In a study on the persistence of pesticides under the impact of pesticide combinations, the addition of benomyl to a flooded soil even at close to field application rate of 5 ppm level significantly increased the persistence of generally less persistent parathion. This increased persistence was a direct consequence of the striking inhibition of biologically mediated nitro-group reduction and hydrolysis of parathion by benomyl. The addition of rice straw hastened nitro-group reduction; but the effect of benomyl in increasing the persistence of parathion was pronounced even in the presence of added rice straw. These studies demonstrate that long term persistence of parathion can occur in situations where it is applied in combination with other pesticides such as benomyl, raising problems of contamination of water resources and inland fisheries.

Sudhakar-Barik, Siddaramappa, R., Sethunathan, N. (1976) Metabolism of nitrophenols by bacteria isolated from parathion-amended flooded soil. *Antonie van Leeuwenhoek* 42: 461–470.

*Summary:* Two bacterial isolates from parathion-amended flooded soil, *Pseudomonas* sp. and *Bacillus* sp., were examined for their ability to decompose nitrophenols. Uniformly labelled  $^{14}\text{C}$ -p-nitrophenol was metabolized by both bacteria,  $^{14}\text{CO}_2$  and nitrite being end products. A substantial portion (23 percent for *Pseudomonas* sp. and 80 percent for *Bacillus* sp.) of radioactivity applied as p-nitrophenol was accounted for as  $^{14}\text{CO}_2$  at the end of a 72-h period 8 to 16 percent remained in the water phase after solvent extraction. *Pseudomonas* sp. produced nitrite also from 2,4-dinitrophenol, but only after a lag, and not from o- and m-nitrophenols. Interestingly, m-nitrophenol, known for its resistance to biodegradation because of meta substitution, was decomposed by *Bacillus* sp., resulting in the formation of nitrite and phenol; o-nitrophenol and 2,4-dinitrophenol resisted degradation by this bacterium.

Suzuki, T. (1983a) Metabolism of pentachlorophenol (PCP) by soil microorganisms. *Bull. Nat. Inst. Agric. Sci. (Japan)* Serie C 38: 69–120.

*Notes:* in Japanese

Suzuki, T. (1983b) Methylation and hydroxylation of pentachlorophenol (PCP) by *Mycobacterium* sp. isolated from soil. *Bull. Nat. Inst. Agric. Sci. (Japan)* Serie C 8: 419–428.

*Notes:* The major pathways of PCP degradation by *Mycobacterium* are determined.

Tomizawa, C. (1975) Degradation of organophosphorus pesticides in soils with special reference to anaerobic conditions, in *Environmental quality and safety*, Coulston, F., Albany, N.Y., Korte, F. (eds.), Academic Press, New York. 117–127 pp. (NC)

Tomizawa, C. (1980) Biological accumulation of pesticides in an ecosystem: Evaluation of biodegradability and ecological magnification of rice pesticides by a model ecosystem. *JARQ* 14(3): 143–149.(NS)

*Notes:* Description of microosm where the fate of BHC is followed in water, algae, snail, fish, rice and cucumber.

Tomizawa, C., Kazano, H. (1979) Environmental fate of rice paddy pesticides in a model ecosystem. *J Environ. Sci. Health* 14B: 121–152.

*Summary:* The distribution and metabolic fate of several rice paddy pesticides were evaluated in a modified model ecosystem. Among the three BHC isomers, beta-isomer was the most stable and bioconcentrated in all of the organisms. Alpha- and gamma-isomers were moderately persistent and degraded to some extent during the thirty-three-day period. Disulfoton was relatively persistent due to the transformation to its oxidation products. Pyridaphenthion was fairly biodegradable. N-Phenyl maleic hydrazide derived from the hydrolysis of pyridaphenthion was not detected in the organism though it was found in the aquarium water after thirty-three days. Cartap and edifenphos were considerably biodegradable, and the ratio of the conversion to water soluble metabolites was very high. There was a distinct different in the persistence of Kitazin P and edifenphos in the aquarium water. It appeared that the hydrolysis rate of the pesticides affected their fate in the organisms. PCP appeared to be moderately biodegradable. CNP was considerably stable and stored in the organisms though the concentration in aquarium water was relatively low. The persistence and distribution of the pesticides in the model ecosystem were dependent on their chemical structures. In spite of the limitation derived from short experimental period, the model ecosystem may be applicable for predicting the environmental fate of pesticides.

*Notes:* The model uses sand instead of soil.

Tsukano, Y., Kobayashi, A. (1972) Formation of gamma-BTC in flooded rice soils treated with gamma-BHC. *Agric. Biol. Chem.* 36: 166–167.(NS)

*Notes:* Gamma BHC in upland soils is degraded into gamma PCCH while, in wetland conditions, gamma BTC is formed which disappears much faster and is therefore difficult to detect.

Venkateswarlu, K. (1979) Microbial degradation of carbamate insecticides in rice soils. Ph.D. thesis, Utkal University, Bhubaneswar. (NC)

Venkateswarlu, K., Gowda, T.K.S., Sethunathan, N. (1977) Persistence and biodegradation of carbofuran in flooded soils. *J. Agric. Food Chem.* 25: 533–536.

*Summary:* The persistence of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methyl carbamate) in four soils was studied in the laboratory with special reference to flooded conditions. After thin-layer chromatographic separation of residues, carbofuran in the soil samples was converted to its phenol by alkaline hydrolysis and then assayed colorimetrically following diazotization. More rapid degradation of carbofuran occurred in soils under flooded conditions than under nonflooded conditions. Carbofuran degraded rapidly between twenty and forty days after flooding in most soils including an acid sulfate saline soil, Pokkali, capable of attaining near neutral pH upon flooding; but the insecticide persisted in another acid sulfate saline soil, Kari, perhaps due to its exceedingly low pH of 4.2, even after several weeks of flooding. Heat treatment of soils prior to incubation increased the persistence of carbofuran under flooded conditions. Moreover, a bacterium isolated from flooded soil by an enrichment technique, decomposed carbofuran in a mineral salts medium. These studies indicate that microorganisms are involved in the degradation of carbofuran in flooded soils.

*Notes:* Between 60 and 70 percent of carbofuran added to three soils was recovered immediately after mixing the pesticide with the soil.

Venkateswarlu, K., Sethunathan, N. (1978) Degradation of carbofuran in rice soils as influence by repeated application and exposure to aerobic conditions following anaerobiosis. *J. Agric. Food Chem.* 26: 1148–1151.

*Summary:* The persistence of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl N-methylcarbamate) in flooded rice soils was studied after its repeated application. Repeated applications of carbofuran to flooded rice soils at rates close to field applications do not seem to favor rapid buildup of the microorganisms capable of decomposing carbofuran. An isotope study showed that

degradation of carbofuran in flooded soils was more rapid under undisturbed conditions than under aerobic conditions provided by shaking. Under continued anaerobiosis of undisturbed flooded soils, the hydrolysis products, carbofuran phenol (2,3-dihydro-2,2-dimethyl-7-hydroxy benzofuran) in particular, accumulated; but when the undisturbed soil was returned to aerobic conditions, the hydrolysis products decreased rapidly.

Venkateswarlu, K., Sethunathan, N. (1979) Metabolism of carbofuran in rice straw-amended and unamended rice soils. *J. Environ. Qual.* 8: 365–368.

*Summary:* Degradation of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl N-methylcarbamate) in rice straw-amended flooded soil under alternate anaerobic-aerobic conditions and  $^{14}\text{CO}_2$  evolution from ring- and carbonyl-labeled  $^{14}\text{C}$ -carbofuran in flooded soil were studied. The addition of rice straw accelerated the hydrolysis of carbofuran to carbofuran phenol (2,3-dihydro-2,2-dimethyl-7-hydroxy benzofuran) in predominantly anaerobic flooded soil. Carbofuran phenol appeared to accumulate under continued anaerobiosis and was readily decomposed with the significant formation of unextractable (“soil bound”) residues when the system was returned to aerobic conditions. Interestingly,  $^{14}\text{CO}_2$  evolution from the aromatic ring in carbofuran was almost negligible, accounting for < 0.3 percent of ring- $^{14}\text{C}$  even after 40 days of flooding as compared to 27 percent released from carbonyl- $^{14}\text{C}$ .

Venkateswarlu, K., Sethunathan, N. (1984) Fate of  $^{14}\text{C}$  carbofuran in a flooded acid sulphate saline soil. *Current science* 53(17): 925–927.(NS)

*Notes:* Test tube experiment showing that carbofuran degradation in an acid saline soil was rapid under flooded conditions, after a lag of about twenty days.

Wahid, P.A., Sethunathan, N. (1978) Sorption-desorption of parathion in soils. *J. Agric. Food Chem.* 26: 101–105.(NS)

Wahid, P.A., Sethunathan, N. (1979) Involvement of hydrogen sulfide in the degradation of parthion in flooded acid sulphate soil. *Nature* (London) 282: 401. (NS)

*Notes:* Hydrogen sulfide formed in flooded soils was at least partly responsible for the formation of the dealkylation product from parathion through aminoparathion.

Wahid, P.A., Sethunathan, N. (1980) Instantaneous degradation of parathion in anaerobic soils. *J. Environ. Qual.* 9: 127–130.

*Summary:* In flooded rice (*Oryza sativa* L.) culture, the pesticides are applied to ricefields after several days of submergence when the soil is already in a reduced state. Parathion (0,0-diethyl O,p-nitrophenyl phosphorothioate) was, therefore, equilibrated with soils previously reduced by flooding with water and then analyzed by isotope technique or by gas-liquid chromatography. Instantaneous surface-catalyzed degradation of parathion occurred when the insecticide was shaken for as little as 5 sec with soils prereduced by flooding. Aminoparathion was the major product of this reaction. The interaction of parathion with pre-reduced soil appeared to be mediated by soil enzymes and/or other heat-labile substances produced by soil anaerobiosis.

Walter-Echols, G., Lichtenstein, E.P. (1978) Movements and metabolism of  $^{14}\text{C}$ -phorate in a flooded soil system. *J. Agric. Food Chem.* 26: 599–604.

*Summary:* Experiments were conducted to study the effects of soil flooding on the fate and metabolism of [ $^{14}\text{C}$ ]phorate in an agricultural loam soil, on the movement and metabolism of the insecticide in a soil-water-plant system, and factors affecting these phenomena. [ $^{14}\text{C}$ ]Phorate residues were readily released from submerged soils into water, amounting to 45 percent of applied radiocarbon during the first three days after flooding. After a two-week incubation period as much as one-half of the radiocarbon applied to the soil was recovered from the water. Phorate was much more persistent under flooded than under nonflooded conditions. It was the principle compound recovered from submerged soils where it accounted for approximately 70 percent of the total residues recovered. Phorate sulfoxide was the major metabolite, only traces of it were detected in the flooded system. However, when *Elodea* plants were introduced into the system, phorate sulfone amounted after fourteen days to 30 percent of all benzene-extractable  $^{14}\text{C}$  residues recovered, phorate sulfoxide to 44 percent, and phorate to 27 percent. At that time soils, water, and plants contained 32, 39, and 17 percent of the applied radiocarbon, respectively. While more lipid-soluble volatile metabolites were recovered from nonflooded soils, more  $^{14}\text{CO}_2$  was evolved from the flooded soil. The production of  $^{14}\text{CO}_2$  was a function of microbiological activity. When [ $^{14}\text{C}$ ]phorate-treated soil was flooded with increasing amounts of water, the amounts of radiocarbon residues in the water increased. However, amounts of  $^{14}\text{C}$  residues in the water decreased when increasing amounts of soil were used.

Wang, C.H., Broadbent, F.E. (1973) Effect of soil treatment on losses of two chloro-nitrobenzene fungicides. *J Environ. Qual.* 2: 511–515. (NS)

*Notes:* Comparison of persistence under upland and flooded conditions. Cited from Sethunathan and Siddaramappa, 1978.

Watanabe, I. (1973a) Decomposition of pesticides by soil microorganisms: Special emphasis on the flooded soil condition. *JARQ Japan Agricultural Research Quarterly* 7(1): 15–18.

*Notes:* Short review with twenty references

Watanabe, I. (1973b) Isolation of pentachlorophenol decomposing bacteria from soil. *Soil Sci. Plat Nutr.* (Tokyo) 19: 109–116.

*Notes:* *Pseudomonas* or closely related strains able to degrade PCP, using it as sole C source, were isolated from a ricefield soil.

Watanabe, I. (1977) Pentachlorophenol-decomposing and PCP-tolerant bacteria in field soil treated with PCP. *Soil Biol. Biochem.* 9: 99–103.

Watanabe, I. (1978) Pentachlorophenol (PCP) decomposing activity of field soils treated annually with PCP. *Soil Biol. Biochem.* 10: 71–75.

*Summary:* Soil from field plots (Hokkaido Agricultural Experiment Station, Memuro, Japan) that had been treated once a year with pentachlorophenol (PCP) and from untreated plots was tested for PCP-decomposing activity in the laboratory. When PCP as an aqueous solution of pentachlorophenolate was added to both sets of soil samples, no significant difference was noticeable in the PCP-decomposing activity, despite a 1,000-fold difference in the number of PCP-decomposing microorganisms. When PCP was added as a PCP-celite mixture—to ensure that PCP was thoroughly mixed with the soil—PCP-decomposing activity was related to the history of the plot's treatment. The activity of the soil from PCP field plots was consistently higher than that from non-treated plots. When PCP was added to the untreated soil and incubated, the number of PCP-decomposing microorganisms increased, reaching the same order as that of PCP-treated soil plots after three to four weeks.

Watanabe, I., Hyashi, S. (1972) Degradation of PCP (Pentachlorophenol) in soil. I. Microbial depletion of PCP under dark and submerged conditions. *J. Sci. Soil Manure Japan* 43: 119–122 [in Japanese]. (NC)

Willis, G.H., Wanter, R.C., Southwick, L.M. (1974) Degradation of trifluralin in soil suspension as related to redox potentials. *J. Environ Qual.* 3: 262–265.

*Summary:* A system for controlling redox potential in soil suspensions was used to investigate the relationship between oxidation-reduction potential (Eh) and the rate of trifluralin (a-a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) degradation. Redox potentials of +450, +250, +150, +50, 0, and –50mV were

imposed on trifluralin-amended (1 ppm oven-dry weight soil basis) soil suspensions (100 g soil in 300 ml H<sub>2</sub>O) for 21 days. Results indicated that exclusion of O<sub>2</sub> by soil flooding initiated rapid trifluralin degradation only when the Eh decreased below a critical range between +150 and +5 -mV. There was no clear-cut relationship between trifluralin degradation and microbiological respiratory activity (CO<sub>2</sub> evolution). If soil flooding is to be a practical cultural technique for accelerating the rate of degradation of persistent pesticides, steps may have to be taken to ensure that soil Eh decreases below a critical value for some required period of time. This may include soil incorporation of a readily available carbon or energy source to stimulate an active soil microbial population to enhance lowering of the soil Eh.

Yamada, T. (1976) Residues of nitrofen and CNP in paddy fields. Pages 217–222 in *Proceedings of the Fifth Asian-Pacific Weed Science Society Conference*, Tokyo.

*Summary:* The residue of herbicide, CNP (P-nitrophenyl 2,4,6-trichlorophenyl ether), and its derivatives: p-aminophenyl 2,4,6-trichlorophenyl ether, 2,4-dichlorophenyl p-nitrophenyl ether (NIP, nitrofen), and p-aminophenyl 2,4-dichlorophenyl ether in paddy field soils were determined. In the paddy field soil sprayed with CNP-granules about ten months ago, large quantities of these amino compounds which combined chemically with the soil organic matters were left over, and they were altered to the free amino compounds by the strong alkaline treatment of the soil samples. The survey of the residues of CNP and NIP, including respective amino derivative, in the paddy field soils in Japan revealed considerably heavy pollution by them, especially in the northern districts.

Yamada, T., Suzuki, S. (1983) Occurrence of reductive dechlorination products in the paddy field soil treated with CPN (Chlomitrofen) *J. Pest. Sci. (Japan)* 8: 437–443.

*Notes:* Dwarf symptoms of rice plant was generated with dechlorinated thiobencarb formed in soil when herbicide thiobencarb was applied at high rate in a field where rice straw had been incorporated. The decomposition of the dechlorinated compound was slower than that of the parent compound.

Yoshida, T. (1975) Pesticide residues in upland rice soils, Pages 200–216 in *Major research in upland rice*, International Rice Research Institute, Los Baños, Philippines. (NC)

*Notes:* A review of the work conducted by IRRI scientists with Philippine soils.



Yoshida, T., Castro, T.F. (1970) Degradation of gamma-BHC in rice soils. *Soil Sci. Soc. Am. Proc.* 34: 440–442.

*Summary:* The biodegradation of the organochlorine insecticide, gamma-BHC (gamma-isomer of 1,2,3,4,5,6-hexachlorocyclohexane) was evaluated for four Philippine rice soils: Casiguran sandy loam, Luisiana clay, Maahas clay and Pila clay loam. Rapid degradation of the insecticide was observed under flooded soil conditions. The rate of degradation for gamma-BHC was highest in Casiguran sandy loam; none of the parent insecticide remained in the soil after one month of incubation at 30°C. Organic matter levels were related directly to rate of decomposition. Molecular oxygen, nitrate, and manganic oxide retarded the rate of gamma-BHC degradation. Increased temperature increased the rate of gamma-BHC degradation, and it appears that gamma-BHC residues are unlikely to be a problem in the tropical rice-growing areas.

Yoshida, T., Castro, T.F. (1975) Degradation of 2,4-D, 2,4,5-T and picloram in two Philippine soils. *Soil. Sci. Plant Nutr.* (Tokyo) 21: 397–404.

*Summary:* The degradation of 2,4-D, 2,4,5-T, and picloram in two Philippine soils was investigated under upland and flooded (submerged) conditions. These herbicides degraded in both upland and flooded Maahas clay and Luisiana clay soils. The rate of degradation of the herbicides was more rapid in the Maahas clay soil than in the Luisiana clay soil. Among the three herbicides, 2,4-D was the least persistent and picloram was the most persistent in both soils under both submerged and upland conditions. 2,4,5-T degraded more actively in the two Philippine soils in this study than studies previously reported in the available literature. The fact that both the 2,4-D and 2,4,5-T did not degrade in sterilized soils during the incubation period suggests that the degradation is due to the microbial activity in the soils.

# APPENDIX B

## ANNOTATED BIBLIOGRAPHY ON PESTICIDE RESIDUES DETECTED IN FISH AND OTHER VERTEBRATES IN RICE-BASED ECOSYSTEMS

R.D. Valmonte-Gerpacio

Argente, A., Seiber, J.N., Magallona, E.D. (1977) Residues of carbofuran in paddy-reared fish (*Tilapia mossambica*) resulting from treatment of rice paddies with furadan insecticides. Paper presented at the eighth National Conference of the Pest Control Council of the Philippines (PCCP), Bacolod City, Philippines.

The study investigated carbofuran residues in 250 *T. mossambica* fingerlings at different times of pesticide exposure. Fish samples were taken two hours before and after treatments. Carbofuran (Furadan 3G) was applied at 2.0 kg ai/ha. Analysis did not show alarming carbofuran residues in live fish after exposure. Even in fish fatally poisoned, residue values were quite low. Carbofuran is neither accumulated in fish nor biomagnified in the food chain on which fish were sustained. No evidence shows that fish exposed to non-fatal doses of carbofuran would contain harmful residues from the exposure. However the possibility of uptake by other biota in the same ecosystem cannot be dismissed.

Cagauan, A.G. (1990) Fish toxicity, degradation period and residues of selected pesticides in rice-fish culture. Paper presented at the Workshop on Environmental and Health Impacts of Pesticide Use in Rice Culture, IRRI, Los Baños, Laguna, Philippines, March 28–30.

The paper presents data on fish toxicity, degradation and residues of selected pesticides in rice-fish culture from studies done at the Freshwater Aquaculture Center, Central Luzon State University (FAC-CLSU), Muñoz, Nueva Ecija. Emphasis however was on Nile tilapia since it is one of the primary fishes recommended for culture in rice-fish farming. Results of several experiments showed that toxicity of insecticides ranged from extreme to moderate while that to herbicides was generally moderate to low. Among the insecticides, MTMC + phenthoate, permethrin and cypermethrin were extremely toxic to Nile tilapia, with 48-hour  $LC_{50}$  values at 0.56, 0.75 and 0.63 ppm respectively. Azinphos-ethyl and monocrotophos were extremely toxic to crucian carp. Most of the carbamates and organophosphates were highly toxic to Nile tilapia while endosulfan was highly toxic to crucian carp. Toxicity of herbicides tested was generally moderate to low except for butachlor which was highly toxic to Nile tilapia.

Six experiments showed that the first application of insecticides prior to fish stocking did not affect the fish but subsequent applications resulted to fish mortality. The former may be due to the dissipation of toxicity. Fish stocking may be done in lower rates of synthetic pyrethroids.

Results from degradation experiments showed that in exposed field conditions, insecticides will degrade faster than in shaded conditions where water temperature is lower. In rice-fish ecosystem, less persistent pesticides may degrade in a shorter period of time when applied to small rice plants than when applied to grown-up plants during late infestation. Any insecticide drift under the heavy rice canopy of grown-up rice plants will degrade longer.

Cruz, E.R., dela Cruz, M.C., Suñaz, N.A. (1988) Hematological and histopathological changes in *Oreochromis mossambicus* after exposure to the molluscicides aquatin and brestan. In Pullin, R.S.V., Bhukaswan, T., Tonguthai, K., Maclean, J.L. (eds.), *The second international symposium on tilapia in aquaculture*. ICLARM Conferenre Proceedings 15, 623 pp. Department of Fisheries, Bangkok, Thailand and ICLARM, Manila, Philippines.

The objective was to determine the ninety-six-hour median lethal concentration ( $LC_{50}$ ) for *Oreochromis mossambicus* of two organostannous molluscicides, Aquatin and Brestan, which are commonly used to control snails in fishponds, and to determine their effects on fish hematology and histopathology. Fish were sampled after twelve, twenty-four, and ninety-six hours of exposure for histopathological analyses of selected tissues. *O. mossambicus* was more sensitive to Brestan. The acute toxicity of both Aquatin and Brestan ceased towards the end of 96 hours. Exposure to lethal concentrations of Aquatin resulted in an

immediate reduction in hemoglobin and hematocrit levels. Hemoglobin content was likewise lower in Brestan-exposed fish, whereas thin hematocrit level was higher than that of the control fish. Histopathological analyses of gills, intestine, liver and kidney showed pathological changes even in sublethal levels tested. Damage became severe with increasing concentration of the pesticides.

Dela Cruz, C.R., Cagauan, A.G. (1981) Preliminary study on the bioassay of seven pesticides and five weedicides with tilapia, carps, clam and shrimp as test species. *Fisheries Research Journal of the Philippines* 6(1): 11–18.

The experiment aimed at determining the median tolerance limit ( $TL_{50}$ ) of various species of aquatic animals, as this can guide fish farmers in selecting the appropriate chemical for pond or ricefields which will not cause mortality of stocked species. The species used were Nile tilapia (*Tilapia nilotica*), crucian carp (*Carassius carassius*), common carp (*Cyprinus carpio*), freshwater shrimp (*Macrobrachium* sp.) and freshwater clam (*Corbicula manilensis*). The insecticides included methyl parathion, carbaryl, BPMC, azinphos ethyl, cypermethrin and permethrin, while the weedicides included MCPA, 2,4-D amine, 2,4-D + piperophos and butachlor. Results showed varying degrees of lethal toxicity of the chemicals used on the different test species. Test species also showed different sensitivity to the same chemicals with which each was subjected. The  $TL_{50}$  of the pesticides only show their relative toxicity on the species. Common carp, shrimps and clam showed high tolerance limits for MCPA and 2,4-D amine. Butachlor appeared relatively toxic to the three species. It can be deduced that tilapia would also be sensitive to butachlor.

Gill, S.S., Yeoh, C.H. (1978) Degradation of carbaryl in the components of the paddy field ecosystem of malaysia. In *Agro-chemical residue-biota interaction in soil and aquatic ecosystem*, Proceedings and Report of a Combined Advisory Group Meeting and Reserved Coordination Meeting, organized by the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture, held in Vienna, Austria. August 28 to September 2.

The experiment studied the fate of N-methylcarbamate, carbaryl in the components of the Malaysian paddy field ecosystem, namely soil, soil extract, and the paddy field fish, *Trichogaster pectoralis*. Samples were collected from paddy fields and irrigation canals and maintained in the laboratory. The microsomal fraction of *T. pectoralis* liver is the major source of enzymes responsible for the metabolism of carbaryl. This essentially follows the metabolism of carbaryl in mammals, plants and insects, and microorganisms. This metabolism of carbaryl is dependent on the presence of  $NADPH_2$ , indicating the importance of mixed function oxidase system in carbaryl degradation by *T. pectoralis* liver. The

soluble fraction also metabolizes carbaryl and the major product is 1-naphtol. It shows the low metabolizing activity in the absence or presence of NADPH<sub>2</sub>.

This lower metabolic activity in *T. pectoralis* would expose the fish to comparatively longer periods of insecticidal action, both at the acute and chronic levels, thus possibly affecting its physiology and reproduction in the paddy-field ecosystem of Malaysia and eventually its population level. Furthermore, this low metabolic activity in the fish could result in higher pesticide residue levels, thereby posing a potential health hazard to the rural population.

Ishikura, Hidetsugu. (1972) *Impact of pesticide use on the Japanese environment. In environmental toxicology of pesticides*. Academic Press, New York.

Cases of fish mortality were reported from twenty-two prefectures out of forty-six in 1954, and from twenty-seven prefectures in 1955. A total of 55.7 percent of the cases were caused by parathion and 21.9 percent by BHC.

With increasing use of parathion to control rice stem borer, swallow population was reported to have decreased in treated areas. Similarly, in areas treated with fenthion, dead sparrows were found. Accordingly, parathion and fenthion were not included in the pesticides recommended for ultra-low volume application.

With respect to the chronic effects of pesticide residues on wildlife, particularly on birds, studies connected on dead birds found in rice-growing areas detected mercury, and reported it as the cause of death.

Isensee, R., Tayaputch, N. (1986) Distribution of carbofuran in a rice paddy-fish microecosystem, Bangkok, Thailand. Paper presented at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27-31.

The study was conducted to determine the behavior and fate of carbofuran under a simulated rice paddy-fish environment and its residues' potential effects on fish. Samples of the mosquito fish (*Gambusia affinis*) were taken at intervals after treating the microecosystem with (6 ppm and 12 ppm) carbofuran. Accumulation of <sup>14</sup>C by mosquito fish was variable and therefore of limited value. However, several trends were noted: a) <sup>14</sup>C extracted from fish with acetonitrile accounted for about 60 percent of the total <sup>14</sup>C in fish on day 3 and then decreased to about 10 percent by 30 days. These results indicate that <sup>14</sup>C was being incorporated into the fish tissues; b) The total of <sup>14</sup>C levels increased continuously with time up to 30 days, with little real loss of <sup>14</sup>C after placement in untreated water for 11 days; 3) Thin layer chromatography (TLC) analysis of fish extracts revealed little, if any, carbofuran. The acute toxicity of carbofuran

to mosquito fish is not known; however, the  $LC_{50}$  values for eight other fish species were all higher than the maximum concentration measured in this study. Hence, carbofuran that entered water at flooding decreased so rapidly that little if any was accumulated by fish.

Jayaraman, J. (1986) Chemodynamics of pesticides: Studies using simulated rice field ecosystem, Madurai Kamaraj University, Madurai, India. Paper presented at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27–31.

The study aimed at understanding the dissipation pattern of pesticides in a ricefield ecosystem, using two models—one static model ecosystem and another, continuous flow model. In the static model ecosystem, malathion was applied at a rate of 40 kg/ha and *Sarotherodon mossambicus* was used as the test organism. Results indicate the fish's tendency to accumulate the pesticide; the maximum level of 0.135 ppm was reached on the fifth day, but this subsequently decreased. In the absence of data on water levels, one can only theorize that this was due to reduced level in water. The overall conclusion however is that the soil acts as a sink, saving the fish from over-exposure.

In the continuous flow model, the chemicals used were endosulfan, dimecron (phosphamidon) and methyl parathion and the test fish species used were *Lepidocephalichthys thermalis* and *Sarotherodon mossambicus*. This experiment showed that both species of fish do not have a tendency to accumulate endosulfan. However, *S. mossambicus*, shows some tendency to accumulate dimecron from water.

Using radioactive pesticides malathion, methyl parathion and carbaryl and isolated systems, it was found that the fish *L. thermalis*, a bottom feeder, and *S. mossambicus* show little tendency to accumulate the pesticides. In the experiment where unlabelled pesticide was used, the residue levels in water is so low and the fact that the fish cannot accumulate them makes malathion a 'safe' pesticide.

Jayaraman, J., Celino, L.P., Lee, K.H., Mohamad, R.B., Sun, J., Tayaputch N., Zhang, Z. (1989) Fate of carbofuran in rice-fish model ecosystem: An international study (India, Philippines, Korea, Malaysia, China and Thailand). *Water, Air and Soil Pollution* 45: 371–375, 1989.

Different fish species were used by the research groups, but in no case is there evidence of bioaccumulation/biomagnification in fish of carbofuran 3G applied at a rate of 0.75 kg ai/ha. Presence of metabolites in small, but nonquantifiable

amounts, suggest that fish can break down the component. Interestingly, the few workers who studied this aspect have all reported that unextractable radioactivity was more than the extractable radioactivity.

Jayaraman, J., and Jebakumar, S.R.D. (1986a) Behavior of  $^{14}\text{C}$ -carbofuran in rice-fish ecosystem, Madurai, India. Paper presented at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27–31.

Carbofuran 3G (0.9 mg ai) was applied at a rate of 30 g/3 kg soil to a rice-fish model ecosystem, into which fish (*Lepidocephalichthys thermalis*) was introduced after seven days. The entire setup was kept in a shaded area, away from direct solar radiation and monsoon rains. Starting from the seventh day, the fish slowly accumulated the compound until fourteen days but decreased thereafter. The ratio of radioactivity between organic extract and water extract shows considerable degradation.

Jayaraman, J., Jebakumar, S.R.D. (1986b) Behavior of  $^{14}\text{C}$ -malathion in a rice-fish model ecosystem, Madurai, India. Paper presented at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27–31.

Fish species used included *Lepidocephalichthys thermalis* and *Oreochromis mossambicus*. None of the biota, either in the field or pond, showed any tendency to accumulate the compounds, and also had a very poor amount of residues. If one were to add up the total malathion present each day in the biotic components, the biphasic curve shows a half-life of even less than two days. The study shows that malathion is safe, in that there is no biomagnification nor bioaccumulation, and that the insecticide has a very short half-life of two or three days only, if chemically extractable residues are considered.

Jayaraman, J., Jebakumar, S.R.D. (1986c) Behavior of phosphamidon (Dimecron) in rice-fish ecosystem, Madurai, India. Paper presented at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27–31.

Dimecron 85 percent EC (phosphamidon) was applied to an experimental tank into which 50 fish (*Lepidocephalichthys thermalis*) were introduced. Fish samples were collected in triplicates by random picking on different days. The maximum residue level of phosphamidon in the fish in the field was detected within 24 hours (1.220 mg/l), which gradually decreased to 0.013 mg/l after four days. Pesticide residues were no longer detectable after ten days.

Kok, L.T., Pathak, M.D. (1966) Toxicity of lindane used for asiatic rice borer control to three species of fish. *Journal of Economic Entomology*, 59(3).

The study was designed to determine the toxicity to fish of lindane used at rates recommended for the control of the Asiatic rice borer. The test fish were in the fingerling stage and were two to four inches long. The three fish species used were tawes (*Puntius javanicus*), tilapia (*Tilapia mossambica*) and carp (*Cyprinus carpio*). Lindane 6 percent (Dol granule) was applied at rates ranging from 0.25 ppm to 4.00 ppm. In laboratory test conducted in aquaria containing water alone, all species suffered high mortality, even at 1.0 ppm lindane. This mortality was remarkably reduced when the tests were conducted in aquaria with a three-inch Maahas clay soil. Furthermore, there was a five to 10 times increase in  $LC_{50}$  values of these species in tests conducted in water 10 cm deep in the field. Lindane toxicity was in the order of tilapia < tawes < carp. All the species had less than four percent mortality when lindane was used at the rate of 2 kg/ha in ponds containing water 10 cm deep. When applied to paddy water, this rate of lindane effectively controls the Asiatic rice borer.

Konar, S.K. (1979) Hazards of water pollution pesticides. In *Environmental pollution and toxicology*, Proceedings of an International Symposium, Haryana Agricultural University and Indian National Science Academy, November 28–30.

For histopathological studies, two fish species, carp (*Labeo rohita*) and singhi (*Heteropneustus fossilis*) were exposed to various levels (from 0.20 ppm to 250 ppm) of four insecticides — DDVP, phosphamidon (organophosphorus), heptachlor (chlorinated hydrocarbon insecticide) and nicotine (plant alkaloid). The fish were exposed for 168 hours and sampled just before death for examination. Histopathological effects found in the fish included cytoplasmic degeneration, collapse of renal tubules, disintegration of nerve and blood cells, rupture of epithelial cells, degeneration of gill filaments, contraction of hepatic cells, among others. The pesticides reduced the digestive enzymes leading to the loss of appetite in fish, hence starving for several days, and reducing fish growth. Intermittent exposure of female fish resulted to abortion of female fish egg laying. The hatching success of fertilized eggs were also detrimentally affected by the presence of pesticides in water.

Madamba, C.S. (1981) Chemodynamics of isoprocarb in the rice paddy environment. M.S. thesis, University of the Philippines at Los Baños, College, Laguna, Philippines, October 1981.

Two- to three-month old *Tilapia nilotica* fingerlings were exposed to 2.0 kg ai/ha of 4 percent isoprocarb and 6 percent hexachlorohexane (Gamma Hytox) to



determine the degradation, metabolism and distribution of isoprocarb in some components of the rice paddy ecosystem. The distribution of radiolabeled isoprocarb was diffuse and was detected one day after exposure. Radioactivity was found concentrated in the head area of the fish, but diffused throughout the upper part of the body. The fish died after two days of exposure.

Medina-Lucero, C. (1980) The dynamics of transport and distribution of two organochlorine (lindane and endosulfan) in a lowland ricefield ecosystem. Doctoral dissertation, University of the Philippines at Los Baños, College, Laguna, Philippines.

The experiment was designed to understand the movement, fate and distribution, and the possible side effects of two organochlorine insecticides in the lowland ricefield ecosystem under natural field conditions, and to assess the ecological impact of the applied insecticides. Lindane (Lindane 6 percent G) and endosulfan (Thiodan 35 percent EC) were applied at 15.2 kg/ha and 0.60 L/ha respectively nineteen and thirty-six days after transplanting IR36 seedlings. The fish species used were tilapia (*Tilapia mossambica*), mudfish (*Ophicephalus striatus*), carp (*Cyprinus carpio*) and catfish (*Clarius batrachus*). Results showed the marked ability of fish to assimilate and accumulate insecticides from their environment. This could be due either to its direct absorption from water or to concentration of residues from food substances. The highly irregular and unpredictable concentration found in the different fish samples may be explained in terms of the physical and environmental variations influencing the extent of absorption, such as the size and age of the fish, duration of its exposure, concentration of the insecticide in the given paddy, and water chemistry.

Mohamad, R.B., Juzu, H.A., Ismail, A.R. (1986) Distribution and fate of  $^{14}\text{C}$ -carbofuran in model rice-fish ecosystem, Serdang, Selangor, Malaysia. Paper presented at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27–31.

The study involved tracing the dynamics of transport, distribution and loss of carbofuran in a rice-fish ecosystem under simulated conditions. Carbofuran was applied at two rates: 0.76 kg ai/ha and 1.90 kg ai/ha, and perch (*Trichogaster trichopterus*) was used as test species. All the fish in the  $^{14}\text{C}$ -carbofuran treated tanks died within twenty-two hours after treatment. Since no fish died in the control tank throughout the experiment period, it showed that perch is susceptible to carbofuran. Results from the analysis of fish could be of limited value due to the fast mortality. Even so,  $^{14}\text{C}$  residues was still detected in the fish. Highest residue concentration was recorded in the head and gills, followed by

entrails and then in the fillet. These indicate that  $^{14}\text{C}$  residues was incorporated into the fish tissue.

Seiber, J.N. (1977) Analysis of carbofuran insecticide on treated rice paddy environments. Paper presented at the Chemical Society of the Philippines Annual Convention, Manila, Philippines, February 22.

Carbofuran (Furadan) granules were applied in the IR20 rice paddy by broadcasting in the paddy water, and by rootzone soil application. Fingerlings of tilapia (*Tilapia mossambica*) or carp were stocked in one meter deep trench in the paddy after transplanting. Fish were harvested before the rice, and fillets were used for residue analysis. Neither broadcast nor rootzone application of carbofuran affected the fish when placed in the paddies seven days after treatment. However, broadcasting carbofuran granules at 1 kg/ha after fish were placed in the pond resulted in 100 percent mortality. Rootzone application proved compatible with fish culture. It increased rice yield and gave additional income to farmers. However, undesirable residues could still contaminate the harvested fish. Residue in fish is 0.05 ppm, which is within the allowable limit of 0.1 ppm. Hence the fish were quite safe for human consumption.

Reyes, I.D., and dela Cruz, C.R. (1983) Degradation rate in water of four agricultural insecticides. *CLSU Science Journal* 3(2): 60–67.

The study was designed to determine the rate at which the efficacy of Azodrin 202 R EC, Brodan EC, Etrofolan WP and Furadan F diminishes in water. Tilapia fingerlings were used as toxicity indicators. Brodan EC was the most toxic insecticide tested and the least degradable compound. Furadan F showed intermediate toxicity and considerable degradation rate, such that it could be used for insect control in rice-fish culture. This requires at least one week time interval to lose its efficacy prior to fish stocking. Azodrin 202 R EC is an effective insecticide which could be applied without the risk of killing fish stock.

Sun, J., Gan, J., Zhang, Y. (1986) Fate of  $^{14}\text{C}$ -carbofuran in model rice-fish and rice-fish-azolla ecosystems, Hangzhou, Zhejiang, China. Paper presented at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27–31.

The safety of using carbofuran in ecosystems and its potential adverse effects to fish was evaluated in two studies involving model ecosystems. In the first study, the model rice-fish (RF) ecosystem,  $^{14}\text{C}$ -carbofuran residues were found in very low quantities in grasscarp (*Crenopharyngodon idella* Vahl.), which declined to

an acceptable limit near harvest. It was found that carbofuran could be degraded or metabolized in components of the rice-fish ecosystem. Ten days after treatment, 3-hydroxy-carbofuran was the predominating metabolite in the plants and fish, whereas in the soil, as in water, carbofuran phenol was found in greater quantities.

The second study, the rice-fish-azolla (RFA) ecosystem, applied carbofuran at a rate of 0.80 kg ai/ha and used tilapia (*Tilapia nilotica* L.) as test species. Considering the relatively small biomass of the fish, the  $^{14}\text{C}$  recovered never exceeded 0.30 percent of the total applied. Also, most of the residues in fish were unextractable, while those extractable were always lower than 0.1 ppm. Fish accumulated a slightly higher amount of carbofuran in the RFA than in the RF ecosystem. Most of the  $^{14}\text{C}$  residues were recovered from the intestines, bones and muscles of the fish.

Sun, J., Gan, J., LI, X., Chen, Z. (1986) Research on the fate of carbofuran in paddy rice/fish ecosystems by radioisotope tracer techniques (III): An insight into bound residues, Hangzhou, Zhejiang, China. Paper presented at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27–31.

Carbofuran (Furanyl-3- $^{14}\text{C}$ ) was applied at a rate of 4.0 kg ai/ha into the system where *Tilapia nilotica* fry are present. Analysis of the bound residues at harvest indicated that the main part of the residues were in binding state. With acid hydrolysis treatment, as much as 91.6 percent of the bound residues in fish were released. It could be concluded that the bound  $^{14}\text{C}$  residues of fish were very labile under acidic condition, and could release  $^{14}\text{C}$  easily. However, the organic soluble portions of the released  $^{14}\text{C}$ -substances in fish (0.90 percent) were very small, indicating that the released residues were water-soluble and of little biological activities.

Tayaputch, N., Kamnerdman, A., Yingchol, Y. (1986) Effect of  $\text{Cl}^{14}$ -carbofuran used in paddy rice to the aquatic environment, Bangkok, Thailand. Paper presented at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27–31.

A microecosystem chamber was set up to study the distribution of carbofuran in the soil, water and fish in a simulated aquatic environment.  $^{14}\text{C}$ -carbofuran (Carbofuran 3G) was incorporated in the rice paddy field soil, where 25-day old RD23 seedlings were transplanted. After two weeks, 12 fish (*Poecilia reticulata*) were released into the tank. The bioavailability and distribution of carbofuran

were evaluated in the system until ninety days. Fish in the rice-fish ecosystem accumulated C14-carbofuran at low levels. The extractable portion was lower than the bound residues. The extractable:unextractable ratio increased from 1:2 at day seven to 1:20 at day 90, indicating that  $^{14}\text{C}$  was being incorporated into the fish tissues.

Tejada, A.W. (1983) The fate of carbofuran in rice paddy ecosystem. Unpublished doctoral dissertation, University of the Philippines at Los Baños, College, Laguna, Philippines.

The study primarily aimed at determining the movement and distribution of carbofuran and its metabolites in the components of a rice paddy ecosystem. Two-week old IR22 rice seedlings were transplanted into a paddy, five days after which the first spraying of carbofuran was done at the recommended rate. Spraying was repeated fifteen, thirty, sixty, and ninety days after transplanting. On the ninetieth day, water from the paddy was drained into the fishpond through a cement pipe to simulate contamination of the lake ecosystem. Analysis showed that the fish entrails had the highest amounts of residue, ranging from 45.1 percent to as high as 68.2 percent, compared to fish head and fillet. The amount gradually decreased within the first week, but later increased until the 30th day. Carbofuran's half-life was estimated to be 13.58 days in fish head; 10.66 days in fish fillet; and 17.32 days in the entrails.

Tejada, A.W., Magallona, E.D. (1985a) Fate of carbofuran in a rice paddy environment. *Philippine Entomology* 6(3): 255–273.

The study was conducted to understand carbofuran's movement, distribution, and loss in the rice paddy ecosystem and thereby assess its pollution potential in the aquatic environment. In the simulated paddy ecosystem, carbofuran was the major metabolite detected. The concentration in water was biomagnified in fish (*Tilapia nilotica*) up to 100 times. The residue was concentrated in the entrails, then in fillet and least in the head. From the half-life value of carbofuran residues in fish (3.8 days), it can be concluded that the pollution potential of this insecticide is small.

Tejada, A.W., Magallona, E.D. (1985b) Fate of carbofuran in a model ecosystem. *Philippine Entomology* 6(3): 275–285.

The study evaluated the pattern of distribution of carbofuran in a model ecosystem. Twenty-four rice seedlings were transplanted into an aquarium and ten one-month old fish were freed on the trench. After five days, 5 ml of carbonyl-labeled carbofuran was sprayed on the rice plants. Samples of water, rice, fish

and air were collected at various time intervals for seven days. The concentration of  $^{14}\text{C}$ -carbosulfan in fish (*Tilapia nilotica*) was biomagnified 400 times in seven days. The bioconcentration factor obtained in the field was lower by two folds, possibly due to dilution effect. The partitioning pattern in decreasing concentration at equilibrium was: soil > water > plant > fish > air.

Tejada, A.W., Magallona, E.D. (1986) Pollution potential of pesticides in agriculture: Rice-fish-livestock farming. Kapisanan ng mga Kimiko sa Pilipinas Los Baiios Chapter, XV Convention, IRRI, Los Baños, Laguna, October 23–24.

The study was conducted to determine which pesticide residues remain in rice at harvest, study its pollution potential and assess the ecological impact. Carbofuran (Furadan G)-treated water was drained into the fish pond, and the uptake, distribution and loss were determined in fish, snails and aquatic plants. The fish bioaccumulated carbofuran residues 68 to 189 times that of residues in water. This is quite low compared to DDT (an organochlorine), which has a bioaccumulation factor of 10,000 to 100,000.

When carbofuran-contaminated leaves were fed to goats for seven consecutive days, it was rapidly excreted in the urine (77 percent). Only one percent of the total residues were eliminated in the feces. About 0.5 percent of the actual dose was secreted in the milk. The total residues were accumulated in different goat tissues but analysis showed that most residues were non-toxic. Contamination of milk and meat were within the FAO/WHO recommendation. Carbofuran residues were also carried into the tissues of the young, but were present in very low amounts. In no case did tissue residues from the later exceed 0.01 mg/kg (the limit set by the procedure). Hence, carbofuran residues were found in levels of no toxicological significance.

Varca, L.M. (1981) Residues of BPMC (2-SEC-Butyl Phenyl N-Methylcarbamate) on some components of a paddy rice ecosystem. M.S. thesis, University of the Philippines at Los Baños, College, Laguna, Philippines.

The thesis aimed at determining the accumulation and distribution of BPMC (carbamate) in the different components of the rice paddy ecosystem following repeated applications, and at assessing BPMC's ecological impact. BPMC was applied at 0.75 kg ai/ha and 250 pieces of *Tilapia mossambica* fingerlings and postfingerlings were used as test species. Residue level present in the fish was not detected after three days. Contamination could have occurred because LC<sub>50</sub> on tilapia was experimentally obtained to be 0.9 mg/kg and no mortality was observed among the fish. The decline of BPMC in different rice paddy components followed pseudo first order kinetics. BPMC is a promising insecticide for

use in rice-fish culture in view of its low toxicity to tilapia and rapid degradation by the fish.

Wang, H., Zhang, Z., Ren, G., Guo, D., Wu, S., Cheng, Z. (1986) Residues of  $^{14}\text{C}$ -monocrotophos in rice-fish ecosystem. Yaan, Sichuan, China. Paper presents at the First FAO/IAEA Research Coordination Meeting on the Use of Isotopes in Studies of Pesticide Residues in Rice/Fish Ecosystems, Bangkok, Thailand, January 27–31.

The study was designed to determine the residue kinetics of monocrotophos in the different components of a model rice-fish ecosystem. Monocrotophos was applied at 0.75 kg ai/ha and common carps were used as test species. At the 28th day after application, accumulation of the monocrotophos in the common carps reached a maximum level of 15.2774 mg/L (standard error = 33.1787). At day 56, this decreased to the minimum level of 6.0551 mg/L (standard error = 2.9455).

Zulkifli, M., Tejada, A.W., Magallona E.D. (1983) The fate of BPMC and chlorpyrifos in some components of a paddy rice ecosystem. Los Baños, Laguna Philippines. *Philippine Entomology* 6(5&6): 555–656.

The study involved the analysis of the fate of BPMC and chlorpyrifos formulation in paddy rice and fish, primarily to give insights on the pollution potential of the compounds as a consequence of use in paddy rice cultivation. Two-week-old IR36 transplanted seedlings were sprayed once with Brodan (BPMC + chlorpyrifos) at 8 ml/3 li 15 days after transplanting. *Tilapia mossambica* samples were taken at intervals after treatment and analyzed. Contamination of pesticide as a spray on non-target organisms such as fish was evident. Chlorpyrifos and BPMC in fish was magnified 8.3 to 58 times that in water. The residue was concentrated in the entrails which is the disposable portion in fish. A five to seven-day interval between spraying and fish harvesting may be considered safe for BPMC and chlorpyrifos, based on  $\text{LC}_{50}$  values.



# APPENDIX C

## ANNOTATED BIBLIOGRAPHY ON THE EFFECTS OF PESTICIDES ON AQUATIC INVERTEBRATES IN RICEFIELDS

LC. Simpson

Papers included in this compilation:

- All papers dealing with studies of pesticides and aquatic invertebrates in ricefields; notes or summaries provided on selected papers;
- Selected papers referring to aquatic invertebrate populations in ricefields;
- Selected papers considering the effects of pesticides on aquatic invertebrates in other freshwater habitats and laboratory experiments;
- Papers containing useful methodologies

A database (ENVIRON) of papers reporting pesticide impacts on non-target organisms in tropical environments is maintained at the Natural Resources Institute, UK. Enquiries to Field Ecology Resource Centre, NRI, Central Avenue, Chatham Maritime, Chatham, Kent, ME4 4TB, UK.

Ali, A.B. (1990) Seasonal dynamics of microcrustacean and rotifer communities in Malaysian ricefields used for rice-fish farming. *Hydrobiologia* 206: 139–148.

*Notes:* The abundance, seasonal dynamics, and species composition of invertebrate communities in ricefields used for rice-cum-fish culture were examined.



In general, copepods were more abundant than cladocerans and rotifers. Relative densities were affected by insecticides and herbicides, predator-prey relationships and the presence of aquatic plants.

Amerasinghe, F.P., Kulasooriya, S.A. (1986) Azolla vs. mosquitoes: Some experiments with *Culex quinquefasciatus*. *MIRCEN J.* 2: 355–363.

Anderson, R.L. (1982) Toxicity of fenvalerate and permethrin to several non-target aquatic invertebrates. *Environ. Entomol.* 11: 1251–1257.

Anderson, R.L. (1983) Insecticide effects on normal development and hatch of embryos of *Paratanytarus parthenogeneticus* (Diptera: chironomidae). *Great Lake Entomol.* 16: 177–181.

Anderson, R.L. (1989) Toxicity of synthetic pyrethroids to freshwater invertebrates. *Environ. Toxicol. Chem.* 8: 403–410.

Apgar, L.A., Meek, C.L., Geaghan, J.P. (1985) Toxicity of riceland agrochemicals on *Thermonectus basillaris* (Harris), a predator of mosquito larvae. *Southwestern Entomol.* 10: 222–227.

*Notes:* The toxic effects of aerially applied pesticides and fertilizers to the predatory beetle *Thermonectus basillaris* (Coleoptera: Dytiscidae) were made in ricefields in Louisiana. Insecticides were significantly more toxic to dytiscids than were fertilizers, fungicides and herbicides. Carbofuran was the most toxic insecticide tested. Fertilizers caused more dytiscid mortality than herbicides and fungicides.

Ban, Y., Kiritani, K. (1980) Seasonal prevalence of aquatic insects inhabiting paddy fields. *Japanese J. Ecol.* 30: 393–400.

Bang, Y.H., Pant, C.P. (1983) A review on disease vectors breeding in ricefields in tropical Asia and research needs. *J. Com. Dis.* 15: 268–279.

*Summary:* In tropical Asia, a number of mosquito species breed in ricefields, many of which are known and potential vectors of malaria, Japanese encephalitis and filariasis. Public health concern caused by the mosquito vectors continues to increase with the expansion of water development schemes for rice production. In view of technical and operational problems encountered in the exclusive use of pesticides, possible natural mortality factors limiting population abundance of mosquitoes in ricefields are identified and reviewed in terms of their economic utilization in an integrated manner. Field research on the

identified mortality factors is suggested so that more effective integration into vector control programmes dealing with mosquito vectors breeding in ricefields can be developed.

Barcelo, D., Sole, M., Durand, G., Albaiges, J. (1991) Analysis and behaviour of organophosphorus pesticides in a rice crop field. *Fresenius J. Anal. Chem.* 339: 676–683.

Barrion, A.T., Litsinger, J.A. (1982) The aquatic invertebrate fauna of IRRRI ricefields. Poster presented at the 13th National Conference of the Pest Control Council of the Philippines, May 5–8, Baguio City, Philippines.

Barrion, A.T., Litsinger, J.A. (1984) Chironomids, corixids and ostracod pests of irrigated rice seedling roots. *Int. Rice Res. Newsl.* 9: 19.

Batalla Perez, J.A. (1971) Sustitutos de los insecticidas organoclorados en la lucha contra los Quironomidos de los arrozales y su toxicidad para la fauna deceacuicola. *Arroz* 12: 14–15,

*Notes:* Translates to—Substitutes for organochloride insecticides in the control of chironomids in ricefields and its toxicity for freshwater fauna.

Bhattacharya, T., Joy, V.C., Joy, S. (1980) Soil inhabiting cryptostigmata (Acari) of the ricefield ecosystem in relation to agro-technical measures. Pages 981–987 in Furtado, J.I. (ed.), *Tropical Ecology and Development*, Proceedings of the International Society of Tropical Ecology, Kuala Lumpur. 1383 pp.

Bhuiyan, S.I., Sheppard, B.M. (1987) Modern rice technology and its relationships to disease vector propagation. In *Effects of agricultural development on vector borne diseases*. FAO Publication AGL/MISC/12/8.

Bown, D.N. (1987) Agricultural use of pesticides and their effect on vector-borne disease transmission in the WHO regions of the Americas. Pages 53–56 in *Effect of agricultural development on vector-borne diseases*. FAO, Rome.

Cabrera, B.D., Miyagi, I., Mogi, M. (1984) Development and survival of immature mosquitoes (Diptera: Culicidae) in Philippine ricefields. *J. Med. Entomol.* 21: 283–291.

Cagauan, A.G., Cruz Dela, C.R., Floroblanco, F., Cruz, EM., Sevilleja, R.C. (1993) Impacts of fish and pesticide in lowland irrigated ricefields. Paper

presented at the Third Regional Rice-Fish Farming Research and Development Workshop, June 6–11, SURF, Sukamandi, Indonesia.

*Notes:* Carbofuran insecticide reduced aquatic oligochaete population densities by 49–80 percent.

Caquet, T., Thybaud, E., le Bras, S., Jonot, O., Ramade, F. (1992) Fate and biological effects of lindane and deltamethrin in freshwater mesocosms. *Aquat. Toxicol.* 23: 262–278.

Chandler, J.A., Highton, R.B. (1975) The succession of mosquito species (Diptera, Culicidae) in ricefields in the Kisumu area of Kenya, and their possible control. *Bull. Ent. Res.* 65: 295–302.

Chandler, G.T., Scott, G.I. (1991) Effects of sediment-bound endosulfan on survival, reproduction and larval settlement of meiobenthic polychaetes and copepods. *Environ. Toxicol. Chem.* 10: 375–382.

Chapman, P.M., Brinkhurst, R.O. (1984) Lethal and sublethal tolerances of aquatic oligochaetes with reference to their use as a biotic index of pollution. *Hydrobiologia* 115: 139–144.

Chapman, P.M., Farrell, M.A., Brinkhurst, R.O. (1982a) Relative tolerances of selected aquatic oligochaetes to individual pollutants and environmental factors. *Aquat. Toxicol.* 2: 47–67.

Chapman, P.M., Farrell, M.A., Brinkhurst, R.O. (1982b) Relative tolerances of selected aquatic oligochaetes to combinations of pollutants and environmental factors. *Aquat. Toxicol.* 2: 69–78.

Cheah, M.L., Avault, J.W., Graves, J.B. (1980) Acute toxicity of selected rice pesticides to crayfish, *Procambarus clarkii*. *Prog. Fish. Cult.* 42: 16–172.

Clement, S.L., Grigarick, A.A., Way, M.O. (1977) The colonisation of California rice paddies by chironomid midges. *J. Appl. Ecol.* 14: 379–389.

Coats, J.R., Symonik, D.M., Bradbury, S.P., Dyer, S.D., Timson, L.K., Atchison, G.J. (1989) Toxicology of synthetic pyrethroids in aquatic organisms: An overview. *Environ. Toxicol. Chem.* 8: 671–680.

Day, K.E. (1989) Acute, chronic and sublethal effects of synthetic pyrethroids on freshwater zooplankton. *Environ. Toxicol. Chem.* 8: 411–416.

Day, K.E. (1990) Pesticide residues in freshwater and marine zooplankton: A review. *Environ. Pollut.* 67: 205–222.

Day, K.E., Kaushik, N.K. (1987) Short-term exposure of zooplankton to the synthetic pyrethroid, fenvalerate, and its effects on rates of filtration and assimilation of the algae, *Chlamydomonas reinhardtii*. *Arch. Environ. Contam. Toxicol.* 16: 423–432.

Day, K.E., Kaushik, N.K., Solomon, K.R. (1987) Impact of fenvalerate on enclosed planktonic communities and on *in situ* rates of filtration of zooplankton. *Can. J. Fish. Aquat. Sci.* 44: 1714–1728.

Denoyelles, F., Kettle, J.W., Fromm, C.H., Moffett, M.F., Dewney, S.L. (1989) Use of experimental ponds to assess the effects of a pesticide on the aquatic environment. *Misc. Publ. Entomol. Soc. Am.* 75: 41–56.

Ernst, W.R., Jonah, P., Doe, K., Julien, G., Hennigar, P. (1991) Toxicity to aquatic organisms of off-target deposition of endosulfan applied by aircraft. *Environ. Toxicol. Chem.* 10: 103–114.

Fashuyi, S.A. (1981) Observations on the ecology of *Bulinus* (*Physopsis*) *globosus* (Morelet), *Bulinus forskalii* (Ehregberg) and *Lymnaea natalensis* (Krauss) in rice swamps in Sierra Leone. *J. Molluscan Stud.* 47: 328–333.

Fernando, C.H. (1971) The ecology of the aquatic fauna of ricefields with special reference to South East Asia. *GEO-ECO-TROP* 1: 169–188.

Fernando, C.H. (1980) Ricefield ecosystems: A synthesis. Pages 939–942 in Furtado, J.I. (ed.), *Tropical Ecology and Development*, Proceedings of the International Society of Tropical Ecology, Kuala Lumpur. 1383 pp.

Fernando, C.H., Furtado, J.I., Lim, R.P. (1979) Aquatic fauna of the world's ricefields. Wallanaceana Suppl. 2. Department of Zoology, University of Malaya, Kuala Lumpur, Malaysia.

*Notes:* A general introduction and bibliography of references (931) to the aquatic fauna of ricefields, with an introduction to the ecology of the ricefield fauna.

Fernando, C.H., Furtado, J.I., Lim, R.P. (1980) The ecology of ricefields with special reference to aquatic fauna. Pages 943–951 in Furtado, J.I. (ed.), *Tropical Ecology and Development*, Proceedings of the International Society of Tropical Ecology, Kuala Lumpur. 1383 pp.

Flickinger, E.L., King, K.K., Stout, W.F., Mohn, M.M. (1980) Wildlife hazards from Furadan 3G applications to rice in Texas. *J. Wildl. Manage.* 44: 190–197.

Fores, E., Comin, F.A. (1988) Action of malathion plus lindane pesticide on crustacean populations. *Ecotoxicol. Environ. Saf.* 15: 180–185.

*Notes:* The effects of malathion plus lindane on *Moina* and *Acanthocyclops* populations were tested under experimental conditions. The dose used by farmers in ricefields of the Ebro River Delta (Spain) is high enough to control copepods and cladocerans. Zooplankton population recovery begins with rotifers followed by crustaceans.

Fox, H.M. (1965) Ostracod crustaceans from ricefields in Italy. *Mem. Ist Ital. Idrobiol.* 18: 273–294.

Fukuhara, H., Kikuchi, E., Kurihara, Y. (1980) The effect of *Branchiura sowerbyi* (Tubificidae) on bacterial populations in submerged ricefield soil. *Oikos* 34: 88–93.

Garcia, E.G. (1988) Control of *Schistosoma japonica* snail, intermediate host in riceland ecosystems. Pages 203–210 in *Vector-borne diseases control in humans through rice agroecosystem management*. IRRI, Los Baños, Philippines.

Georghiou, G.P. (1987) The effects of agrochemicals on vector population. In *Effects of agricultural development on vector-borne diseases*, FAO Publication AGL/MISC/12/87.

Gersich, F.M., Bartlett, E.A., Murphy, P.G., Milazzo, D.P. (1989) Chronic toxicity of Biphenyl to *Daphnia magna* Straus. *Bull. Environ. Contam. Toxicol.* 43: 355–362.

Gorbach, S., Haaring, R., Knauf, W., Werner, H.J. (1971a) Residue analysis in the water system of East-Java (River Brantas, ponds, sea-water) after continued large-scale applications of Thiodan in rice. *Bull. Environ. Contam. Toxicol.* 6: 40–47.

Gorbach, S., Haaring, R., Knauf, W., Werner, H.J. (1971b) Residue analysis and biotests in ricefields of East Java treated with Thiodan. *Bull. Environ. Contam. Toxicol.* 6: 193–199.

Grant, I.F., Alexander, M. (1981) Grazing of blue-green algae (Cyanobacteria) in flooded soils by *Cypris* sp. (Ostracoda). *Soil Sci. Soc. Am. J.* 45: 713–777.

*Summary:* Grazing by the microcrustacean, *Cypris*, on five species of  $^{14}\text{C}$  labelled N-fixing blue-green algae (cyanobacteria) in flooded soils indicated diet preferences among the algae. Animal size and floodwater temperature markedly affected feeding rates, but pH had little effect from pH 5.0 to 10.0. Control of feeding was achieved with low concentrations of lindane. Cell size of the blue-green algae was not apparently responsible for diet selection, but cell age was significant with two species. It is suggested that nitrogen fixation by blue-green algae in paddy fields may be increased by using inocula of algae not suitable for active grazing or by suppressing grazing by means of insecticides.

Grant, I.F., Egan, E.A., Alexander, M. (1983a) Pesticides to control ostracod grazing on blue-green algae. *Soil Biol. Biochem.* 15: 193–197.

*Summary:* Means to control ostracod grazing on blue-green algae (cyanobacteria) important in fixing nitrogen in flooded rice soils were studied. The relative acute lethal toxicity (48 hr  $\text{LC}_{50}$ ) to the ostracods *Cyprinotus carolinensis* and *Heterocypris luzonensis* grazing on *Tolypothrix tenuis* was 0.4 and 2.4  $\mu\text{g/ml}$  for carbofuran and 4.5 and more than 56.0  $\mu\text{g/ml}$  for lindane. Complete inhibition of grazing was achieved with 1.0 and 25  $\mu\text{g}$  carbofuran/ml and 0.1 and 5.6  $\mu\text{g}$  lindane/ml for *C. carolinensis* and *H. luzonensis*, respectively. Lindane at concentrations below 0.02  $\mu\text{g/ml}$  stimulated feeding by *C. carolinensis* on the alga. Breakdown of carbofuran markedly reduced its effectiveness as a measure to control grazing, but lindane did not rapidly lose its effectiveness. The toxicity of carbofuran to *C. carolinensis* feeding on *T. tenuis* was not affected by pH. The difference in ostracod responses to the pesticides, which may be associated with resistance acquired through previous exposure, is an important consideration in designing practical means to reduce grazing in paddy fields.

Grant, I.F., Egan, E.A., Alexander, M. (1983b) Measurement of rates of grazing of the ostracod *Cyprinotus carolinensis* on blue-green algae. *Hydrobiologia* 106: 199–208.

Grant, I.F., Roger, P.A., Watanabe, I. (1985) Effect of grazer regulation and algal inoculation on photodependent nitrogen fixation in a wetland ricefield. *Biol. Fertil. Soils* 1: 61–72.

*Summary:* A dry season field experiment conducted for two consecutive years highlighted problems of achieving increased populations of N-fixing blue-green algae (BGA) in wetland ricefields. Inoculation of non-indigenous BGA strains, either dried or as fresh viable inocula even at high levels of application was unsuccessful. A limiting effect of grazing invertebrate populations on BGA establishment was evident, but other factors were involved. Reducing grazer

pressure did not permit establishment of inoculated BGA; interspecific competition and environmental factors may explain the inoculation failure. Grazer regulation permitted the establishment of a fast-growing indigenous N-fixing *Anabaena* and the doubling of N-fixing activity over a control. Neither inoculation nor grazer control affected grain yields significantly.

Grant, I.F., Roger, P.A., Watanabe, I. (1986) Ecosystem manipulation for increasing biological nitrogen fixation by blue-green algae (Cyanobacteria) in lowland ricefields. *Biol. Agri. Hort.* 3: 299–315.

Grant, I.F., Seegers, R. (1985a) Movement of straw and algae facilitated by tubificids (*Oligochaeta*) in lowland rice soil. *Soil Biol. Biochem.* 17: 729–730.

Grant, I.F., Seegers, R. (1985b) Tubificid role in soil mineralisation and recovery of algal nitrogen by lowland rice. *Soil Biol. Biochem.* 17: 559–563.

Grant, I.F., Seegers, R., Watanabe, I. (1983) Increasing biological nitrogen fixation in flooded rice using neem. Proc 2nd Int Neem Conf. *Rauischholzhausen*: 493–506.

*Summary:* The antifeedant properties of neem extracts to *Heterocypris luzonensis* Neale (Ostracoda) were investigated. These aquatic crustaceans are particularly successful in colonizing wetland ricefields, where they can limit the establishment, growth and nitrogen-fixing activities of blue-green algae.

Passive aqueous extracts of neem seeds and Soxhlet extractions of neem seed or cake in acetone or water did not affect grazing of *H. luzonensis* on *Tolypothrix tenuis* (Cyanophyta) within 2 h of exposure. However, passive aqueous extracts of neem seed substantially reduced grazing after 4 days of exposure. A 1.6 ppm aqueous solution of a crude extract of *Azadirachta* (15–18 percent in acetone) inhibited feeding completely and instantaneously.

Greenhouse pot experiments were designed to study the effect of alleviating ostracod grazing pressure on N<sub>2</sub>-fixing blue-green algae by applying neem seed and neem cake to the floodwater. Total nitrogen (N) inputs and outputs of the plant/soil/water system were measured over five rice harvests and the positive N balances obtained were attributed to biological N<sub>2</sub>-fixation. A highly significant and large positive N balance was obtained in soils treated with neem seed. Neem cake applications did not increase N balance significantly when compared with an untreated control. When algal growth was prevented by covering soils with a black cloth, only a small N balance was maintained. Nitrogen uptake by grain and straw from pots treated with or without neem seed or cake was similar, but that from soils covered by a black cloth was 30 percent less. Neem had no

direct effect upon growth of the rice plant. Effects of neem application on N balance were considered with reference to N fixation, antifeedant properties, and inhibition of nitrification.

Grant, I.F., Tirol, A.C., Aziz, T., Watanabe, I. (1983) Regulation of invertebrate grazers as a means to enhance biomass and nitrogen fixation of Cyanophyceae in ricefields. *Soil Sci. Soc. Am. J.* 47: 669–675.

*Summary:* The effect of invertebrate grazing on the growth and N fixation of blue-green algae (Cyanophyceae) in flooded rice soils was investigated by depressing grazer populations. Grazers were controlled with commercial pesticides and neem seeds (*Azadirachta indica*). Algal N fixation and standing biomass were estimated by acetylene-reduction activity and chlorophyll *a* measurements. Suppression of ostracod (Ostracoda) grazing by Perthane or neem seeds tripled blue-green algae biomass and increased N fixation rates 10-fold. In the absence of ostracods, free living blue-green algae multiplied rapidly early in the rice cultivation cycle to be succeeded by chlorophytes. Carbofuran was not an effective control measure. Suppression of molluscan grazing had little effect. The population of tubificids (Tubificidae) was higher in the plots where algal growth was stimulated than in other plots. Total rice grain N was increased up to 37 percent when grazing was arrested.

Grigarick, A.A., Webster, R.K., Meyer, R.P., Zalom, F.G., Smith, K.A. (1990) Effects of pesticide treatments on non-target organisms in California rice paddies. I. Impact of Triphenyltin hydroxide. *Hilgardia* 58: 1–36.

*Summary:* An application of triphenyltin hydroxide at 1.16 kg ai/ha to ricefields for stem rot (*Sclerotium oryzae* Catt.) control results in a significant reduction of 57 percent of the invertebrate taxa and 67 percent fewer individuals based on two collecting methods that sampled the nekton, neuston, and benthon. Populations of herbivores, carnivores, and filter feeders were sharply reduced after treatment, most remained so through the twenty-eighth day following application. By day 50 many of the winged species recovered in both numbers and diversity. However, recovery of benthic organisms was slower or not at all for most Crustacea. An initial reduction followed by a strong resurgence was noted for the mosquito *Culex tarsalis* Coq., which was probably due to the significant reduction of five predaceous species.

Habito, C.D. (1990) Effect of pesticide use on the zooplankton populations in a ricefield ecosystem. Paper presented at the workshop on the Environmental and Health Impacts of Pesticide Use in Rice Culture, March 28–30, IRRI, Los Baños, Philippines: 7 pp.



*Notes:* Pesticide impact studies on zooplankton populations in farmers' ricefields were inconclusive.

Halwart, M. (1993) Fish in Ricefields. Pages 54–69 in Milan, P.P., Magraf, J. (eds.), *Philippine freshwater ecosystems*. Tropical Ecology Program, Visayan State College of Agriculture, Baybay, Leyte, Philippines.

Hanazato, T. (1991) Effects of repeated application of carbaryl on zooplankton communities in experimental ponds with or without the predator *Chaoborus*. *Environ. Pollut.* 0269–7491/91:309–324.

Hanazato, T., Yasuno, M. (1990a) Influence of *Chaoborus* density on the effects of an insecticide on zooplankton communities in ponds. *Hydrobiologia* 194: 183–197.

Hanazato, T., Yasuno, M. (1990b) Influence of persistence period of an insecticide on recovery patterns of a zooplankton community in experimental ponds. *Environ. Pollut.* 67: 109–122.

Hanazato, T., Yasuno, M. (1990c) Influence of time of application of an insecticide on recovery patterns of a zooplankton community in experimental ponds. *Arch. Environ. Contam. Toxicol.* 19: 77–83.

Hashimoto, Y. (1982) Effects of pesticides on aquatic organisms and their environment. *J. Pest. Sci.* 7: 281–287.

Hatakeyama, S., Shiraishi, H., Kobayashi, N. (1990) Effects of aerial spraying of insecticides on non-target macrobenthos in a mountain stream. *Ecotoxicol. Environ. Saf.* 19: 254–270.

Hatakeyama, S., Shiraishi, H., Sugaya, Y. (1991) Monitoring of the overall pesticide toxicity of river water to aquatic organisms using a freshwater shrimp *Paratya compressa improvisa*. *Chemosphere* 22: 229–235.

*Notes:* Bioassays were conducted in rivers adjacent to rice cultivation. During peak periods of aerial spraying four day mortality was 100 percent, but quickly dropped to 0 percent.

Hatakeyama, S., Sugaya, Y. (1989) A freshwater shrimp (*Paratya compressa improvisa*) as a sensitive test organism to pesticides. *Environ. Pollut.* 59: 325–336.

Heckman, C.W. (1974) A season succession of species in a rice paddy in Vientienne, Laos. *Int. Rev. Ges. Hydrobiol.* 59: 489-507.

Heckman, C.W. (1979) Ricefield ecology in northeastern Thailand. The effect of wet and dry seasons on a cultivated aquatic ecosystem. *Monographiae Biologicae* 34, J. Illies (ed.) Junk W Pub, The Hague. 228 pp.

Heckman, C.W. (1982) Pesticide effects on aquatic habitats. *Environ. Sci. Tech.* 16: 48-57.

*Notes:* The paper includes a review of pesticide impacts in rice growing areas in Asia.

Helegen, J.C., Larson, N.J., Anderson, R.L. (1988) Response of zooplankton and *Chaoborus* to Temephos in a natural pond and in the laboratory. *Arch. Environ. Contam. Toxicol.* 17: 459-471.

Hendrick, R.D., Bonner, F.L., Everett, T.R., Fahey, J.E. (1966) Residue studies on aldrin and dieldrin in soil, water and crawfish from ricefields having insecticide contamination. *J. Econ. Ent.* 59: 1388-1391.

*Notes:* Accumulations of aldrin, dieldrin and DDE were found in the crawfish *Procambarus clarkii* reared in contaminated paddies. Aldrin residues were several times greater than in the soil.

Hill, I.R. (1989) Aquatic organisms and pyrethroids. *Pestic. Sci.* 27: 429-457.

Hirata, H., Yamasaki, S., Kohirata, E. (1984) Effects of benthocarb herbicide on growth of planktonic organisms *Chlorella sacchurophila* and *Brachionus plicatilis*. *Memoirs Faculty of Fisheries, Kagoshima University* 33: 51-56.

Holck, A.R., Meek, C.L. (1987) Dose-mortality responses of crawfish and mosquitoes to selected pesticides. *J. Am. Mosq. Control. Assoc.* 3: 407-411.

*Notes:* Toxicities of selected pesticides to crawfish and mosquito species common in Louisiana ricefields were determined in laboratory experiments.

Hurlbert, S.H., Mulla, M.S., Kieth, J.O., Westlake, W.E., Dusch, M.E. (1970) Biological effects and persistence of Dursban in freshwater ponds. *J. Econ. Entomol.* 63: 43-51.

Hurlbert, S.H., Mulla, M.S., Wilson, H.R. (1972) Effects of an orthophosphorus insecticide on the phytoplankton, zooplankton and insect populations of fresh-water ponds. *Ecol. Monogr.* 42: 269–299.

Iizuka, H. (1989) Fate and persistence of herbicides applied to paddy fields in aquatic environment. *Bull. Nat. Inst. Ago-Environ. Sci.* 6: 1–18.

Ikeshoji, T. (1980) Emergence of chironomid midges in four differently fertilized paddies. *Jap. J. Sanit. Zool.* 31: 201–208.

Ishibashi, N., Itoh, S. (1981) Effects of herbicide benthocarb on fauna in paddy field (Jpn). *Proc. Assoc. Plant Prot. Kyushu* 27: 90–93.

*Summary:* The three-time application of herbicide benthocarb through the rice growing period was investigated on fauna in the soil and flood water in the rice paddies. Nematodes in soil: There were no significant differences in the total number of individuals collected between the treated and control. However, herbicide application gave rise to an increase in plant-parasitic, fungivorous and bacteriophagous nematodes with conspicuous decrease in predacious ones of which habitat was mainly aerobic layer. Aquatic animals in flood water in paddy field: Shortly after benthocarb treatment, midges, tadpoles, pond snails, water fleas, dragonfly nymphs and mosquito larvae were drastically decreased. However, midges, mosquito larvae and algaephagous water fleas (*Branchiopoda*, *Moina* sp.) multiplied rapidly to exceed each population size in non-treated control, corresponding to the conspicuous retardation of recovering population sizes of predators such as hydrophilids, dragonfly nymphs and Copepoda.

Iwakuma, T., Takamura, K., Nohara, S. (1988) Dynamics of benthic communities in tributaries of the River Koise in relation to residual pesticides. *Res. Rep. Nat. Inst. Environ. Stud.* 114: 85–100.

Iwakuma, T., Takamura, K., Nohara, S., Shiraishi, H. (1993) Dynamics of benthic communities in relation to pesticide concentrations in small rivers receiving agricultural runoff. Paper presented at the First Society of Environmental Toxicology and Chemistry World Congress, Ecotoxicology and Environmental Chemistry—a global perspective, Lisbon, Portugal, March 28–31.

*Notes:* Zoobenthos, attached algae and pesticide residues were studied in streams receiving runoff from paddy fields. Residual organophosphate insecticides and herbicides seemed to lower the density of *Baetis*. Chironomids and oligochaetes were apparently unaffected.

Jambari, H.A., Rosli, B.M. (1993) Freshwater snails: A good candidate for toxicity studies of agrochemicals used in tropical paddy ecosystem. Paper presented at the First Society of Environmental Toxicology and Chemistry World Congress, Ekotoxicology and Environmental Chemistry: a global perspective, Lisbon, Portugal, March 28–31.

*Notes:* It was concluded that snails would be good candidates for toxicity studies to aquatic organisms in tropical paddy ecosystems because they are easy to handle and culture, and sensitive to carbamate and organophosphate pesticides.

Jindal, R., Singh, J. (1989) Toxicity of pesticides to the productivity of a freshwater pond. *Indian J. Environ. Health* 31: 257–261.

Keilty, T.J., Landrum, P.F. (1990) Population-specific toxicity responses by freshwater oligochaete, *Stylodrilus heringianus*, in natural Lake Michigan sediments. *Environ. Toxicol. Chem.* 9: 1147–1154.

Keilty, T.J., White, D.S., Landrum, P.F. (1988a) Sublethal exposure to endrin in sediment by *Stylodrilus heringianus* (Lumbriculidae) as measured by a cesium marker layer technique. *Aquat. Toxicol.* 13: 251–279.

Keilty, T.J., White, D.S., Landrum, P.F. (1988b) Sublethal responses to endrin in sediment by *Limnodrilus hoffmeisteri* (Tubificidae), and in mixed culture with *Stylodrilus heringianus* (Lumbriculidae). *Aquat. Toxicol.* 13: 227–250.

Keilty, T.J., White, D.S., Landrum, P.F. (1988) Short-term lethality and sediment avoidance assays with endrin contaminated sediment and two oligochaetes from Lake Michigan. *Arch. Environ. Contam. Toxicol.* 17: 95–101.

Khudairi, S.Y.A., Ruber, E. (1974) Survival and reproduction of ostracods as affected by pesticides and temperature. *J. Econ. Entomol.* 67: 22–24.

Kikuchi, E., Furusaka, C., Kurihara, Y. (1975) Surveys of the fauna and flora in the water and soil of paddy fields. *Rep. Inst. Agr. Res. Tohoku Univ.* 26: 25–35.

Kikuchi, E., Furusaka, C., Kurihara, Y. (1977) Effects of tubificids (*Branchiura sowerbyi* and *Limnodrilus socialis*) on the nature of a submerged soil ecosystem. *Jap. J. Ecol.* 27: 163–170.

Kikuchi, E., Kurihara, Y. (1977) *In vitro* studies on the effects of tubificids on the biological chemical and physical characteristics of submerged ricefield soil and overlying water. *Oikos* 29: 348–356.

Kikuchi, E., Kurihara, Y. (1981) Effects of tubificids on the biological and chemical characteristics of submerged ricefields ecosystems. *Verh. Internat. Verein. Limnol.* 21: 1194.

Kikuchi, E., Kurihara, Y. (1982) The effects of the oligochaete *Branchiara sowerbyi* Beddard (Tubificidae) on the biological and chemical characteristics of overlying water and soil in a submerged ricefield soil system. *Hydrobiologia* 97: 203–208.

Kim, Y.H., Lee, S.K., Yoo, S.A., Chang, C.Y., Kim, W. (1993) Ecological risk evaluation of pesticides used in rice paddies. Paper presented at the First Society of Environmental Toxicology and Chemistry World Congress, Ecotoxicology and Environmental Chemistry: a global perspective, Lisbon, Portugal, March 28–31.

*Notes:* Diazinon and chlorpyrifos affected the individual numbers and species diversity of macroinvertebrates. Butachlor, cartap, diazinon, IBP and chlorpyrifos affected individual numbers and species diversity of zooplankton and algae.

Koeman, J.H., Pennings, J.H., Rosanto, R., Soemarwoto, O., Tjioe, P.S., Blancke, S., Kusumadinata, S., Djajadiredja, R.R. (1974) Metals and chlorinated hydrocarbon pesticides in samples of fish, sawah-duck eggs, crustaceans and molluscs collected in Indonesia in West and Central Java, Indonesia. Institute of Ecology, Padjadjaran University, Bandung. 14 pp.

Kreutzweiser, D.P., Capell, S.S. (1992) A simple stream-side test system for determining the acute lethal and behavioural effects of pesticides on aquatic insects. *Environ. Toxicol. Chem.* 11: 993–999.

Krishnan, M., Chockalingam, S. (1989) Toxic and sublethal effects of endosulfan and carbaryl on growth and egg production of *Moina micrura* Kurz (Cladocera: Moinidae). *Environ. Pollut.* 56: 319–326.

Kurasawa, H. (1956) The weekly succession in the standing crop of plankton and zoobenthos in the paddy field (Jpn). *Shigen Kagaku Kenshyusho Iho* 45: 86–99.

Kurihara, Y. (1989) Ecology of some ricefields in Japan as exemplified by some benthic fauna, with notes on management. *Int. Rev. Ges. Hydrobiol.* 74: 507–548.

*Summary:* The role of tubificids and mud snails in the ricefield ecosystem was elucidated using their ecology as a basis for highlighting problems in the strategy of recycling between agricultural and urban activities.

Tubificid oligochaetes occur in high densities in ricefields where irrigation water is polluted with sewage, high organic matter content is present in the soil and when highly toxic insecticides are not used. High tubificid densities reduce and even eliminate weeds, change the composition and density of bacteria and increase the density of zooplankton. Also they serve as a high quality source of food for fish comparable to that of insects. Conditions that promote a healthy growth of tubificids obviate or reduce the need for weedicides and high levels of inorganic fertilizers.

Mud snails which thrive in ricefields have been used as an important source of protein food for humans in rural Japan. The snails can consume a sludge-reed compost mixture used as a fertilizer in ricefields. However, the high heavy metal content in the sludge is accumulated by the snails which are thus unfit for human consumption. Based on these results and the known ecology of tubificids and the snails, a possible recycling system comprising sewage sludge, reeds, fish, insects and egrets using these two kinds of benthic organisms is proposed.

Kurihara, Y., Kadowaki, K.I. (1988) Effect of different ecological conditions on the mud snail (*Cipangopaludina japonica*) in submerged paddy soil. *Biol. Fertil. Soils* 6: 292–297.

Kurihara, Y., Kikuchi, E. (1980) Analysis of interactions among biotic and abiotic factors in ricefields, with special reference to the role of tubificids in the ricefield ecosystem. Pages 1017–1019 in Furtado, J.I. (ed.), *Tropical Ecology and Development*, Proceedings of the International Society Tropical Ecology, Kuala Lumpur. 1383 pp.

Kurihara, Y., Kikuchi, E. (1988) The use of tubificids for weeding and aquaculture in paddy fields. *J. Trop. Ecol.* 4: 393–401.

Kurihara, Y., Suzuki, T., Moriyama, K. (1987) Incorporation of heavy metals by the mud snail *Cipangopaludina chinensis malleata* Reeve, in submerged paddy soil treated with sewage sludge. *Biol. Fertil. Soils* 5: 93–97.

Lee, K.W. (1979) The effects of Thiodan, 2,4-D and Sevin 85 on the plankton community and fish in a rice-field system. M.S. thesis, University of Malaya. 272 pp.

Lim, R.P. (1980) Population changes of some aquatic invertebrates in ricefields. Pages 971–980 in Furtado, J.I. (ed.), *Tropical Ecology and Development*, Proceedings of the International Society Tropical Ecology, Kuala Lumpur. 1383 pp.

*Summary:* The effects of pesticide application on the aquatic invertebrate community in ricefields was studied over two growing seasons. A total of 39 taxa were collected over the two growing seasons. The dominant groups were the nematodes, ostracods, conchostracans, ephemeropterans, hemipterans and dipterans which comprised an average of 93% of the total fauna. In the plots that were untreated with pesticides nematodes, hemipterans and dipterans dominated while in plots treated with pesticides ostracods, dipterans and conchostracans predominated. Temporal changes, community structure and population of the invertebrate community were affected not only by pesticide application but by ploughing, fertilisation and transplanting, and the development of aquatic macrophytes. Heterogeneity decreased with the above mentioned perturbations. Only the application of the carbofuran had any significant effect in decreasing the invertebrate population. Overall the population was higher in the pesticide treated plots. This was due to *inter alia* to the rapid recruitment of ostracods.

Lim, R.P. (1992) Effects of pesticides on the aquatic invertebrate community in ricefields. *Malay. Nat. J.* 45: 336–352.

Lim, R.P., Abdullah, M.F., Fernando, C.H. (1984) Ecological studies of cladocera in ricefields of Tanjung Karang, Malaysia, subject to pesticide treatment. *Hydrobiol.* 113: 99–103.

*Summary:* Temporal changes in the population densities of four dominant Cladocera (*Moina micrura*, *Diaphanosoma excisum*, *Alona guttata*, and *Macrothrix spinosa*) were studied in untreated and pesticide treated rice plots over a growing season. *M. micrura* was the first dominant species to occur in all the plots which were initially devoid of vegetation except for the newly transplanted rice seedlings. With the growth of the rice seedlings and the appearance of aquatic macrophytes, open water ricefields were transformed into vegetated littoral conditions precipitating the disappearance of *M. micrura* and the appearance of the littoral *A. guttata* and *M. spinosa*, and the eurytopic *D. excisum*. The cladoceran community was affected by spraying of the pesticide FMC35001, an analogue of Furadan. The response of the four dominant species to the pesticide treatment is discussed.

Lim, G.S., Heong, K.L. (1984) The role of insecticides in rice integrated pest management. Pages 19–39 in *Judicious and efficient use of insecticides on rice*. IRRI, Los Baños, Philippines.

Lim, R.P. Wong, M.C. (1986) The effects of pesticides on the population dynamics and production of *Stenocypris major* Baird (Ostracoda) in ricefields. *Arch. Hydrobiol.* 106: 421–427.

*Summary:* The population densities and production of the ostracod, *Stenocypris major* Baird, were studied in untreated and pesticide treated rice plots in Malaysia based on the randomised block design. The treated plots were sprayed on three occasions with a carbofuran, FMC 35001 at 0.2 percent ai/ha and an endosulfan, Thiodan 5G at 1.5 kg ai/ha. The population density of ostracods was twice as high in the carbofuran treated plots (avg. 21,591 indiv/sq m) when compared with the control (avg. 10,770 indiv/sq m), while the population density in the endosulfan treated plots was half that of the control (avg. 4,398 indiv/sq m). Similarly production of ostracods was higher in the carbofuran treated plots with an average of 35.41 mg/sq m/day while that of the endosulfan treated plots was lower with an average of 5.42 mg/sq m/day when compared with the control which had an average of 21.46 mg/sq m/day. The implications of these findings are discussed.

Magallona, E.D. (1989) Effects of insecticides in rice ecosystems in Southeast Asia. Pages 265–297 in Bourdeau, P., Haines, J.A., Klein, W., Krishna Murti, C.R. (eds.), *Ecotoxicology and climate*, Wiley.

*Notes:* Chapter describing the evolution of insecticide use in Southeast Asian rice culture, physico-chemical characteristics of the ecosystem and their effect on insecticides. Main emphasis is on the impact of individual compounds on pests, parasitoids, predators, pathogens and other non-target organisms. Includes an extensive bibliography.

Mani, V.G.T., Konar, S.K. (1988) Pollution hazards of the pesticide chlorpyrifos on the aquatic ecosystem. *Environ. Ecol.* (India) 6: 460–462.

Machbub, B., Ludwig, H.F., Gunaratnam, D. (1988) Environmental impact from agrochemicals in Bali (Indonesia). *Environ. Monitor. Assess.* 11: 1–23.

Maund, S.J., Peither, A., Taylor, E.J., Juettner, I., Bayerle-Pfnuer, R., Lay, J.P., Pascoe, D. (1992) Toxicity of lindane to freshwater insect larvae in compartments of an experimental pond. *Ecotoxicol. Environ. Saf.* 23: 76–88.

McKenzie, K.G., Moroni, A. (1986) Invasions by Ostracoda (Crustacea) into the Italian ricefields ecosystem. Page 153 in Groves, R.H., Burdon, J.J. (eds.), *Ecology of biological invasions*. Cambridge University Press, Cambridge.

Mather, T.H., Trinh Ton That. (1984) *Environmental management for vector control in ricefields*. Irrigation and drainage paper 41. FAO, Rome.



Mian, L.S., Mulla, M.S. (1992) Effects of pyrethroid insecticides on non-target invertebrates in aquatic ecosystems. *J. Agric. Entom.* 9: 73–98.

*Notes:* Review paper citing 75 references of the effects of pyrethroid insecticides on aquatic invertebrates.

Miura, T., Takahashi, R.M. (1974) Insect development inhibitors. Effects of candidate mosquito control agents on non-target aquatic organisms. *Environ. Entomol.* 3: 631–636.

Miura, T., Takahashi, R.M., Wilder, W.H. (1981) The selected aquatic fauna of a ricefield ecosystem with notes on their abundance, seasonal distributions and trophic relationships. *Proc. Papers Ann. Conf. Calif. Mosq. Vector Contr. Assoc.* 49: 68–72.

Mochida, O. (1987) *Pomacea* snails in the Philippines. *Int. Rice Res. Newsl.* 12: 48–49.

Mogi, M. (1979) Dispersal of *Culex tritaeniorhynchus* larvae (Diptera: Culicidae) by water currents in ricefields. *Trop. Med.* 21: 115–126.

Mogi, M. (1987) Effect of changing agricultural practices on the transmission of Japanese encephalitis in Japan. Pages 93–100 in *Effect of agricultural development on vector-borne diseases*, FAO, Rome.

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Mogi, M., Wada, Y. (1973) Spatial distribution of larvae of the mosquito *Culex tritaeniorhynchus summorosus* in a ricefield area. *Trop. Med.* 15: 69–83.

Mohsen, Z.H., Ouda, N.A., al-Faisal, A.H., Mehdi, N.S. (1985) Toxicity of mosquito larvicides to backswimmer, *Anisops sardea* (Hemiptera: Heteroptera: Notonectidae) and dragonfly *Corothemis erythraea* (Odonata: Libellulidae). *J. Biol. Sci. Res.* 16: 273–282.

*Notes:* *Culex quinquefasciatus* was found to be resistant to DDT and malathion, but sensitive to temephos, idofenphos and permethrin. DDT, malathion and permethrin were highly toxic to backswimmers and dragonfly larvae. It was concluded that temephos was the best candidate for mosquito larvae control with least damage to predatory species.

Mulla, M.S., Darwazeh, H.A., Dhillon, M.S. (1980) New pyrethroids as mosquito larvicides and their effects on non-target organisms. *Mosq. News* 40: 6–12.

*Notes:* Five new synthetic pyrethroids were tested against six mosquito species. They were mostly very effective against fourth instar larvae and pupae. In field trials mayfly larvae were very susceptible, diving beetles, damselflies and dragonflies were slightly affected, but microcrustaceans were apparently unharmed.

Mulla, M.S., Majori, G., Arata, A.A. (1979) Impact of biological and chemical mosquito control agents on non-target biota in aquatic ecosystems. *Res. Rev.* 71: 121–173.

Mullie, W.C., Verwey, P.J., Berends, A.G., Sene, F., Koeman, J.H., Everts, J.W. (1991) The impact of Furadan 3G (carbofuran) applications on aquatic macroinvertebrates in irrigated rice in Senegal. *Arch. Environ. Contam. Toxicol.* 20: 177–182.

*Summary:* The impact of Furadan 3G applications (carbofuran, granular formulation, dose rate 1 kg ai/ha) on aquatic macroinvertebrates was studied in irrigated test plots with rice in northern Senegal. Total biomass of macroinvertebrates and numbers of Odonata, Ephemeroptera, Nematocera (Diptera), and Hydrocorisae (Hemiptera) were severely and significantly reduced after treatment, and remained significantly lower than those in control plots until at least twenty-four days after treatment. No effects could be demonstrated on Veliidae (Hemiptera), Coleoptera, and Arachnida. In an *in situ* bioassay, Ephemeroptera was the most sensitive taxon, showing 50 percent mortality at eighteen to nineteen days after treatment. Side-effects of carbofuran applications were also observed in frogs and birds; some birds that consumed spilled granules died immediately.

Furadan 3G applications, as practiced in the region, caused dramatic effects on many nontarget organisms. Its use is hazardous to wildlife, and it severely reduces the significance of irrigated ricefields as a feeding habitat for birds, including waders, and other insectivorous organisms.

Muirhead-Thompson, T.C. (1971) Impact of pesticides on aquatic invertebrates in nature. In *Pesticides and freshwater fauna*. Academic Press, London.

Naqvi, S.M.Z. (1973) Toxicity of twenty-three insecticides to a tubificid worm *Branchiura sowerbyi* from the Mississippi Delta. *J. Econ. Entomol.* 66: 70–74.

Neale, J.W. (1977) Ostracods from rice-fields of Sri Lanka (Ceylon). *Sixth International Ostrocod Symposium*, Saalfelden.

Neugebauer, K., Zieris, F.J., Huber, W. (1990) Ecological effects of atrazine on two outdoor artificial freshwater ecosystems. *Z. Wasser-Abwasser-Forsch.* 23: 11–17.

Ocampo, P.P., Varca, L.M., Tejada, A.W. (1990) Pesticide residues in vertebrate and invertebrate organisms in rice-agroecosystems. Paper presented at the workshop on the Environmental and Health Impacts of Pesticide Use in Rice Culture, March 28–30, IRRI, Los Baños, Philippines. 9 pp.

Osa-Afiana, L.O., Alexander, M. (1981) Factors affecting predation by a microcrustacean (*Cypris* sp.) on nitrogen-fixing blue-green algae. *Soil Biol. Biochem.* 13: 27–32.

Pal, A.K., Konar, S.K. (1989) Effects of chronic exposure of phosphamidon on aquatic ecosystems. *Environ. Ecol.* 7: 708–712.

Prot, J.C. (1990) Pesticides in the food chain in ricefields. Paper presented at the workshop on the Environmental and Health Impacts of Pesticide Use in Rice Culture, March 28–30, IRRI, Los Baños, Philippines. 11 pp.

Prot, J.C., Matias, D.M. (1990) Impact of pesticides on *Hirschmanniella oryzae* and *Hirschmanniella mucronata* in ricefields in Laguna Province, Philippines. Paper presented at the workshop on the Environmental and Health Impacts of Pesticide Use in Rice Culture, March 28–30, IRRI, Los Baños, Philippines. 11 pp.

*Notes:* Among eleven insecticides, three herbicides, and two molluscicides used in thirty-three irrigated ricefields only momocrotophos and ethofenprox provided limited evidence of impacts on nematode population density.

Ree, H.I. (1982) Studies on sampling techniques of the mosquito larvae and other aquatic invertebrates in the ricefield. *Korean J. Entomol.* 12: 37–43.

Reynoldson, T.B., Thompson, S.P., Bamsey, J.L. (1991) A sediment bioassay using the tubificid oligochaete *Tubifex tubifex*. *Environ. Toxicol. Chem.* 10: 1061–1072.

Roger, P.A., Bhuiyan, S.I. (1990) Ricefield ecosystem management and its impact on disease vectors. Pages 2–18 in Biswas, A. (ed.), *Water Resources Development 6*, Butterworth, Oxford.

*Notes:* This paper reviews (1) the major features of the ricefield as an ecosystem for vectors of selected diseases, (2) the effects of the factors of crop intensification on vectors, and (3) the possible methods of vector control through management of the ecosystem which includes water management, especially the alternate wetting and drying method, conservation of natural enemies, utilization of pesticides of plant origin, and biological control by predators and pathogens.

Roger, P.A., Grant, I.F., Reddy, P.M. (1985) *Blue-green algae in India: A trip report*. IRRI, Los Baños, Philippines.

Roger, P.A., Grant, I.F., Reddy, P.M., Watanabe, I. (1987) *The photosynthetic aquatic biomass in wetland ricefields and its effect on nitrogen dynamics. Efficiency of nitrogen fertilizers for rice*. IRRI, Los Baños, Philippines.

Roger, P.A., Heong, K.L., Teng, P.S. (1991) Biodiversity and sustainability of wetland rice production: role and potential of microorganisms and invertebrates. Pages 117–136 in Hawksworth, D.L. (ed.), *The biodiversity of microorganisms and invertebrates: Its role in sustainable agriculture*. CABI, Wallingford.

Roger, P.A., Kurihara, Y. (1988) Floodwater biology of tropical wetland ricefields. Pages 275–300 in *Proceedings of the First International Symposium on Paddy Soil Fertility*, Int. Soil Sci. Soc., The Hague.

Roger, P.A., Jimenez, R., Oficial, R., Ardales, S., Simpson, L.C. (1990) Survey of microbial biomass, blue-green algae and tubificid populations in ricefields of the Laguna region (Philippines) with regard to pesticide utilization. Paper presented at the workshop on the Environmental and Health Impacts of Pesticide Use in Rice Culture, March 28–30, IRRI, Los Baños, Philippines. 43 pp.

Roger, P.A., Santiago-Ardales, S. (1991) *USAID funded subproject on nitrogen-excreting blue-green algae*, Final Report, IRRI, Los Baños, Philippines. 63 pp.

Roger, P.A., Simpson, I., Oficial, R., Ardales, S., Jimenez, R. (1992) Bibliographic and experimental assessment of the impacts of pesticides on soil and water microflora and fauna in wetland ricefields. In *Proceedings of the International Rice Research Conference*, April 21–25, IRRI, Los Baños, Philippines.

Roger, P.A., Watanabe, I. (1987) Some microbiological and hydrobiological environmental effects of new rice technology. Paper presented at the workshop on environmental and socioeconomic impacts of new rice technology, December 1–4, IRRI, Los Baños, Philippines.

Rossi, O., Moroni, A., Baroni, P., Caravello, U. (1974) Annual evolution of the zooplankton diversity in twelve Italian ricefields. *Bull. Zoo.* 41: 157–181.

Sasmal, S., Kulshrestha, J.P. (1984) Chemical control of the snail *Lymnaea auricularia* (L) race *swinhoi* (H Adams), a pest of *Azolla pinnata*. *Rice Res. Newsl.* 5: 2.

Sasmal, S., Kulshrestha, J.P. (1987) Biology and control of the snail *Lymnaea auricularia* (L) race *minhoei* (H Adams), a pest of *Azolla pinnata*. *Oryza* 24: 177–179.

Sastrodihardjo, S., Adiarto, M., Yusoh, M.D. (1978) The impact of several insecticides on soil and water communities. *Proc Southeast Asian workshop on Pesticide Management*, Bangkok, Thailand: 117–125.

Sato, H., Yasuno, M. (1979) Test on chironomidae larvae susceptibility to various insecticides. *Jap. J. Sanit. Zool.* 30: 361–366.

Saxena, P.N., Saxena, S.C. (1986) Acute toxicity of malathion to dragonfly (*Bradinopyga geminata*) larvae, the non-target insect species. *Indian Biol.* 18: 18–19.

Schaeffer, C.H., Miura, T. (1990) Chemical persistence and effects of S31183, 2-1, methyl-2-4-phenoxyphenoxyethoxypyridine on aquatic organisms in field tests. *J. Econ. Entomol.* 83: 1768–1776.

Schaeffer, C.H., Miura, T., Dupras, E.F., Wilder, W.H., Mulligan, F.S. (1988) Efficacy of CME134 against mosquitoes (Diptera: Culicidae): Effects on non-target organisms and evaluation of potential chemical persistence. *J. Econ. Entomol.* 81: 1128–1132.

Notes: Ricefield copepods and cladocerans suffered substantial mortality when CME134 was applied at very low concentrations, but populations recovered within a few days.

Schaeffer, C.H., Miura, T., Stewart, R.J., Dupras, E.F. (1983) Studies of the potential environmental impact of the herbicide thiobencarb (Bolero). *Proc. 50th Ann. Conf. Calif. Mosq. Vector Control Assoc.*: 89–98.

Self, L.S. (1987) Agricultural practices and their bearing on vector-borne diseases in the WHO western Pacific Region. Pages 48–56 in *Effect of agricultural development on vector-borne diseases*. FAO, Rome.

Senapati, B.K., Biswal, J., Pani, S.C., Sahu, S.K. (1992) Ecotoxicological effects of malathion on earthworms. *Soil Biol. Biochem.* 24: 1719–1722.

Senapati, B.K., Biswal, J., Sahu, S.K., Pani, S.C. (1991) Impact of malathion on *Darwida willsi* Michaelsen, a dominant earthworm in ricefields. *Pedobiologia* 35: 117–128.

*Notes:* Results suggest that *Darwida willsi* responds to malathion applications by increasing reproductive activity, secondary production and turnover, thus compensating for increased mortality.

Sibley, P.K., Kaushik, N.K., Kreutzweiser, D.P. (1991) Impact of pulse application of permethrin on the macroinvertebrate community of a headwater stream. *Environ. Pollut.* 70: 35–55.

Simpson, I.C. (1993) The impact of agricultural practices on the aquatic invertebrate populations of ricefields. Ph.D. thesis, University of Wales College of Cardiff.

*Notes:* Evidence of stimulatory and inhibitory pesticide effects were found on aquatic oligochaete populations in experimental plots, but not in farmers' fields. In plot experiments, there was little evidence of carbofuran and butachlor impacts on ostracods, copepods, cladocerans, dipteran larvae and/or benthic snail populations. Ostracods in a greenhouse experiment were initially adversely affected by carbofuran and Perthane, but generally recovered quickly.

Simpson, L.C. (1993) The impact of agricultural practices on the aquatic invertebrate food supply of fish in ricefields. Paper presented at the Third Regional Rice-Fish Farming Research and Development Workshop, June 6–11, SW, Sukamandi, Indonesia.

*Notes:* The application of the pesticides carbofuran and butachlor at realistic rates did not markedly effect populations of microcrustaceans, dipteran larvae or

against *Chironomus tepperi*. All treatments caused initially high mortality with the exception of diazinon. Temephos showed the least residual activity with no mortality after five days, while chlorfenvinphos showed the longest with 61.5 percent mortality after fifteen days.

Takahashi, R.M., Miura, T., Wilder, W.H. (1982) A comparison between the area sampler and the two other sampling devices for aquatic fauna in ricefields. *Mosq. News* 42: 211-216.

Takamura, K., Hatakeyama, S., Shiraishi, H. (1991) Odonata larvae as an indicator of pesticide contamination. *Appl. Entomol. Zool.* 26: 321-326.

*Notes:* The abundance of odonate larvae was surveyed in a river system surrounded by ricefields. Species diversity and numbers were lower at downstream stations.

Takamura, K., Nohara, S., Kariya, T., Okazaki, M., Ito, K. (1991) Effects of pesticide contamination from ricefields on stream benthic arthropods. *Jap. J. Limnol.* 52: 95-103.

*Notes:* The composition of benthic arthropod communities, concentrations of pesticide residues and river water toxicity for the shrimp *Paratya compressa* and the minnow *Tanichtys albonubes* were surveyed at five stations before and after transplanting rice into paddy fields. The abundance of *Baetis thernicus* decreased with pesticide concentration.

Takamura, K., Yasuno, M. (1986) Effects of pesticide application on chironomid larvae and ostracods in ricefields. *Appl. Ent. Zool.* 21: 370-376.

*Summary:* Benthic macroinvertebrates were surveyed in ricefields in which three pesticide applications were adopted; no pesticide, herbicide only, and herbicide + insecticide + fungicide. Abundant taxa were chironomid and ostracod. The populations of these animals fluctuated widely in the pesticide-treated ricefields. Larval populations of odonates and dytiscids which prey on chironomid larvae and ostracods, were depressed when pesticides were applied. The low density of predators presumably allowed the large increase in the populations of chironomids and ostracods. However, competition between chironomids and ostracods, as well as the direct toxic effects of pesticides, may have suppressed the increase of their numbers to some degree. Benthic algae decreased with most applications of herbicide. The algae showed a slight increase probably due to heavy grazing by chironomids and ostracods and to herbicide toxicity in the pesticide-treated fields.

benthic molluscs. Aquatic oligochaetes were adversely affected by carbofuran application during one dry season, but not during the following year.

Simpson, I.C., Roger, P.A., Oficial, R., Grant, I.F. (1993a) Density and composition of aquatic oligochaete populations in different farmers' ricefields. *Biol. Fertil. Soils* 16: 34–40.

*Notes:* The density and composition of ricefield oligochaete populations were estimated in thirty-three farmers' fields in the Philippines and related to physico-chemical properties of the soils and agrochemical use. No pesticide impacts were observed.

Simpson, I.C., Roger, P.A., Oficial, R., Grant, I.F. (1993b) Impacts of agricultural practices on aquatic oligochaete populations in ricefields. *Biol. Fertil. Soils* 16: 27–33.

*Notes:* The impacts of N fertilizer, pesticides and green manure on aquatic oligochaetes in irrigated ricefields were investigated in experimental plots. An inhibitory effect of carbofuran on oligochaete populations was observed during the first season of experimental pesticide treatments, but not during the following year.

Simpson, I.C., Roger, P.A., Oficial, R., Grant, I.F. (1994a) A study of the effects of nitrogen fertilizer and pesticide management on floodwater ecology in wetland ricefields: I. Experimental design and dynamics of the photosynthetic aquatic biomass. *Biol. Fertil. Soils* 17: 129–137.

Simpson, I.C., Roger, P.A., Oficial, R., Grant, I.F. (1994b) A study of the effects of nitrogen fertilizer and pesticide management on floodwater ecology in wetland ricefields: II. Dynamics of microcrustacean and dipteran larvae. *Biol. Fertil. Soils* 17: 138–146.

*Notes:* Microcrustacean and dipteran larvae populations were monitored over a crop cycle in the floodwater of a tropical ricefield subject to various nitrogen management and pesticide regimes. When considered at the crop cycle level, populations were not significantly affected by applications of butachlor and/or carbofuran.

Singh, A., Agarwal, R.A. (1992) Toxicity of the latex of Euphorbiales: Effects on acid and alkaline phosphates of the snail *Lymnaea acuminata*. *Biol. Argi. Hort.* 8: 211–219.



Singh, P.K., Pal, S., Kumar, K., Triar, S.B., Singh, R. (1986) An effective molluscicide for grazing snails of blue-green algae. *J. Entomol. Res.* 10: 116–118.

Smith, K.A., Grigarick, A.A. (1990) Effects of pesticide treatments on non-target organisms in California rice paddies. 11. Impact of Diflubenzuron and Triflumuron. *Hilgardia* 58: 1–36.

*Summary:* Two benzoylphenyl ureas, diflubenzuron and triflumuron, were evaluated in California ricefields to determine their ecological impact on populations of non-target organisms. Modified minnow traps, drag net, and Kellen dredge sampling devices were used in the collecting. Non-target populations were sampled continuously throughout much of the 1985 and 1986 rice growing season. Total collections of non-targets showed only two Cypris species of seed shrimp crustaceans were significantly ( $P<0.05$ ) reduced over time due to either chemical. One predaceous water boatman, *Corisella decolor*, showed the opposite pattern in that populations were significantly ( $P<0.05$ ) lower in the control. Significant differences were not observed in species diversity.

Smith, G.E., Ison, B.G. (1967) Investigation of the effects of large-scale applications of 2,4-D on aquatic fauna and water quality. *Pest. Monitor. J.* 1: 16.

Solomon, K.R., Stephenson, G.L., Kausik, N.K. (1989) The effects of methoxychlor on zooplankton in freshwater enclosures: influence of enclosure size and number of applications. *Environ. Toxicol. Chem.* 8: 659–670.

Srinivasan, S. (1981) Control of daphnia in blue-green algae multiplication plots. *Int. Rice Res. Newsl.* 6: 16.

Stephenson, R.R. (1982) Aquatic toxicology of cypermethrin. 1. Acute toxicology to some freshwater fish and invertebrates in laboratory tests. *Aquat. Toxicol.* 2: 175–185.

Stephenson, G.L., Kaushik, N.K., Solomon, K.R., Day, K. (1986) Impact of methoxychlor on freshwater communities of plankton in limnocorrals. *Environ. Toxicol. Chem.* 5: 587–603.

Stevens, M.M. (1984) Insecticide treatments used against a rice bloodworm, *Chironomus tepperi* (Diptera: Chironomidae): Toxicity and residual effects in water. *J. Econ. Entomol.* 84: 795–800.

*Notes:* The toxicity and persistence of selected organophosphates in ricefields were evaluated by testing water samples taken at intervals after application

Tejada, A.W., Varca, L.M., Calumpang, S.F., Medina, J.B., Bajet, C.M., Paningbatan, E., Medina, J.R., Habito, C., Martinez, M., Magallona, E.D. (1993) Assessment of the environmental impact of pesticides used in rice production. Paper presented at the First Society of Environmental Toxicology Chemistry World Congress, Ecotoxicology and Environmental Chemistry: a global perspective, Lisbon, Portugal, March 28–31.

*Notes:* Populations of zooplankton, algae and beneficial arthropods were initially depressed by pesticide applications, but recovered later.

Thirumurh, S., Palaniswamy, P., Subramaniam, T.R., Kannammal, S. (1973) Effect of aerial spraying on non-target organisms inhabiting rice swamps. *Madras Agric. J.* 60: 873–874.

*Notes:* Mortalities of aquatic vertebrates and invertebrates were estimated after aerial spraying.

Tidou, A.S., Moreteau, J.C., Ramade, F. (1992) Effects of lindane and deltamethrin on zooplankton communities of experimental ponds. *Hydrobiologia* 232: 157–168.

Victor, R., Fernando, C.H. (1980) Freshwater ostracoda from the ricefields of South East Asia. Pages 957–970 in Furtado, J.I. (ed.), *Tropical Ecology and Development*, Proceedings of the International Society of Tropical Ecology, Kuala Lumpur. 1383 pp.

Vidrine, M.F., McLaughlin, R.E., Willis, O.R. (1987) Aquatic snails (Mollusca: Gastropoda) of southwestern Louisiana ricefields. *Proc. La. Acad. Sci.* 50: 16–17.

Wada, Y. (1974) *Culex tritaeniorhynchus*. Pages 105–118 in Pal, R., Wharton, R.H. (eds.), *Control of arthropods of medical and veterinary importance*, Plenum, New York.

Walton, W.E., Darwazeh, H.A., Mulla, M.S., Schreiber, E.T. (1990) Impact of selected synthetic pyrethroids and organophosphorus pesticides on the tadpole shrimp, *Triops longicaudatus* (Le Conte) (Nostraca: Triopsidae). *Bull. Environ. Contam. Toxicol.* 45: 62–68.

*Notes:* Experiments were performed to identify a compound to control the tadpole shrimp which did not interfere with subsequent larvicide (mosquito) trials.

Watanabe, I., DeDatta, S.K., Roger, P.A. (1988) Nitrogen cycling in wetland soils. In Wilson J.R. (ed.), *Advances in nitrogen cycling in agricultural ecosystems*. CABI, UK: 239–256.

Watanabe, I., Roger, P.A. (1985) Ecology of flooded ricefields. Pages 229–243 in *Proceedings of the Workshop on Wetland Soils: Characterisation, Classification, and Utilization*. IRRI, Los Baños, Philippines.

Wayland, M. (1991) Effect of carbofuran on selected macroinvertebrates in a prairie parkland pond: an enclosure approach. *Arch. Environ. Contam. Toxicol.* 21: 270–280.

Wayland, M., Boag, D.A. (1990) Toxicity of carbofuran to selected macroinvertebrates in prairie ponds. *Bull. Environ. Contam. Toxicol.* 45: 74–81.

Webber, E.C., Bayne, D.R., Seesock, W.C. (1989) Macroinvertebrate communities in Wheeler Reservoir (Alabama) tributaries after prolonged exposure to DDT contamination. *Hydrobiologia* 183: 141–155.

Weerekoon, A.C.J., Samarasinghe, E.L. (1958) Mesofauna of the soil of a paddy field in Ceylon. Preliminary survey, *Ceylon J. Sci. (Bio. Sci.)* 1: 156–170.

Whitley, L.S. (1968) The resistance of tubificid worms to three common pollutants. *Hydrobiologia* 32: 193–205.

Whitten, B.K., Goodnight, C.J. (1966) Toxicity of some common insecticides to tubificids. *J. Water Pollut. Control Fed.* 38: 227–235.

Wilson, J.T., Greene, S., Alexander, M. (1980) Effects of microcrustaceans on blue-green algae in flooded soil. *Soil Biol. Biochem.* 12: 237–240.

Wong, M.C. (1979) The ecology of the ostracod, *Stenocypris major* (Baird 1859) with reference to the application of insecticides, carbofuran and endosulfan. B.S. honour thesis, University of Malaya, Malaysia. 77 pp.

Yano, K., Miyamoto, S., Chu, Y.I. (1982) Faunal and biological studies on the insects of paddy fields in Asia. VI. Aquatic and semiaquatic Heteroptera from Taiwan. *Chin. J. Entomol.* 2: 1–13.

Yano, K., Miyamoto, S., Gabriel, B.P. (1981) Faunal and biological studies on the insects of paddy fields in Asia. IV. Aquatic and semiaquatic Heteroptera from the Philippines. *Esakia* 16: 5–32.

Yasumatsu, K., Hashimoto, H., Chang, Y.D. (1979) Chironomid fauna of Korea and their role in the rice agroecosystem. *Int. Rice Res. Newsl.* 4: 17–18.

Yasuno, M., Hanazato, T., Iwakuma, T., Takamura, K., Ueno, R., Takamur, A.N. (1988) Effects of permethrin on phytoplankton and zooplankton in an enclosure ecosystem in a pond. *Hydrobiologia* 159: 247–258.



# APPENDIX D

## ANNOTATED BIBLIOGRAPHY ON THE EFFECTS OF PESTICIDES ON PHOTOTROPHIC MICROORGANISMS OF RICEFIELDS

P.A. Roger

The first part of the compilation is annotated bibliography presenting 311 references dealing with the effects of pesticide on ricefield algae. Papers selected in this compilation include

- All papers dealing with studies of pesticides and algae conducted in ricefields, or with ricefield soil, or *in vitro* with strains isolated from ricefields;
- Considering the importance of blue-green algae for the N fertility of ricefields, all papers dealing with BGA and pesticides; and
- A limited number of papers of interest for methodological aspects or with data useful for comparison.

The second part presents summarized information on the effects of the pesticides tested on ricefield algae. This information is arranged according to pesticides. It also includes basic information on the pesticides tested.

Tabulated values of the recommended doses of pesticides tested are presented in the third part of the compilation.

This information is also available in two Hypercard stacks. The first stack (370 Kbytes) is a bibliographic database. Figure D.1 presents an example of a card on this stack. The second stack (130 Kbytes) compile information according

| New pesticide algae                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                  | Card N° 15/311 | done<br>PERS : Rept. |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|----------------|----------------------|
| Arvik JH, Willson DL, Darlington LC (1971) Response of soil algae to picloram-2,4-D mixtures. Weed Sci 19(3)276-278                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                  |                |                      |
| Key Words                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Field, in vitro, Herbicide, VIP, |                |                      |
| Address                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                  |                |                      |
| <p>Author summary: The effects of an approximate 1:4 commercial mixture of 4-amino-3,5,6-trichloropicolinic acid (picloram) and (2,4-dichlorophenoxy) acetic acid (2,4-D) on a natural population of soil algae were studied at dosages of 0.28, 0.56, and 1.12kg/ha of picloram. No change in the composition of the algal flora was noted over an 18-month period, regardless of dosage. In vitro studies indicated that mixtures of picloram and 2,4-D inhibited growth of <i>Chlorella vulgaris</i> Beyer. at concentrations above 100 ppm, but concentrations above 250 ppm were needed for growth inhibition of <i>CylindrospERMum licheniforme</i> (Bory) Kuetz. or <i>Chlorococcum</i> sp. Picloram alone inhibited all three algae at 50 ppm, while 2,4-D produced no inhibitory effects at concentrations less than 400 ppm. Notes: Very few studies have compared in situ and in vitro effects of pesticides. In a</p> |                                  |                |                      |
| <div> <span>Redistribute</span> <span>Key Word</span> <span>Get ref.</span> <span>Get notes.</span> <span>Push</span> <span>Request</span> <span>Database</span> <span>Navig</span> </div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                  |                |                      |

Figure D.1. Example of a Card of the Bibliographic Database on Hypercard

to pesticides and summarizes the recorded effects on a grid (Figure D.2). Both databases are linked and allow cross-reference.

## Part 1. Bibliographic Compilation

- NS (no summary) The original paper has no summary.  
 NC (not consulted) The paper was not available to the author and is cited from another paper.  
 Abstract The document cited is only an abstract, not a full paper.  
 Summary The summary or abstract included in the original paper.  
 Notes Short summary or comments by the author of this compilation

Adamson, R.P., Sommerfield, M.R. (1980) Laboratory comparison of the effectiveness of several algicides on isolated swimming pool. *Appl. Environ. Microbiol.* 39(2): 348-353.

*Summary:* The most frequently encountered species of algae found in swimming pools in the Phoenix metropolitan area were used to evaluate the laboratory effectiveness of five commercially available pool chemicals used for algal control. The pool algae used were the xanthophyte *Pleurochloris pyrenoidosa*,





and 2,4-bis (isopropylamino)-6-methylmercapto-s-triazine (prometryne) following 6 days of incubation. Water extracts of diuron from soil assayed with this organism were highly correlated with diuron added to the soil. Similar correlations for oats (*Avena sativa* L.) grown on the soil and for diuron in the water extracts as dichloroaniline serve to substantiate the relative effectiveness of the method. Assay of soil samples from field residue plots taken 150 days after herbicidal application showed that active residues of diuron and prometryne were detectable by the organism. Although the chemical method was faster, it has the disadvantage of measuring any dichloroaniline residues rather than only the active residues. The method developed insures a considerable saving in time over herbicide assays involving higher plants and gives reasonably good quantitative data on low concentrations of toxic monuron, diuron, and prometryne.

Adhikary, S.P. (1989) Effect of pesticides on the growth, photosynthetic oxygen evolution and nitrogen fixation of *Westiellopsis prolifica*. *J. Gen. Appl. Microbiol.* 35(4): 319–326.

*Summary:* We examined the effect of the pesticides Furadan (Carbofuran, 3 percent), Sevin (Carbaryl, 50 percent), Rogor (Dimethoate, 30 percent EC) and (Endosulfan, 35 percent EC) on the survival, growth, photosynthetic oxygen evolution, and nitrogen fixation of the cyanobacterium *Westiellopsis prolifica*. Lower concentrations of the carbamate and organophosphate pesticides (10 ppm) increased the growth and nitrogen fixation while higher concentrations (> 20 ppm) had an inhibitory effect. The organochlorine pesticide Endotaf was toxic even at 10 ppm. Survivability and nitrogen fixation of cyanobacterium was reduced to 72 and 93 percent respectively in the presence of 100 ppm of Endotaf. An exposure of the filaments to over 100 ppm of Furadan, Sevin or Rogor caused about a 40 percent inhibition of the photosynthetic oxygen evolution. Endotaf was more toxic than the other pesticides. Oxygen evolution was totally suppressed after incubation of the organism with over 250 ppm of Endotaf; there was similar suppression of O<sub>2</sub> evolution on treatment with more than 500, 1,000, and 1,500 ppm of Rogor, Sevin and Furadan respectively.

*Notes:* Pesticide concentrations are apparently indicated in ppm of commercial formulation and not as active ingredient. Following data are expressed as ppm ai; Effect was estimated as dry weight measured *in vitro* fifteen days after inoculation. Carbofuran had no significant effect until 3 ppm, 50 percent inhibition was at 7.5 ppm, total inhibition was at 30 ppm. Sevin had no significant effect until 50 ppm, 50 percent inhibition was at 125 ppm, total inhibition was at 500 ppm. Rogor had no significant effect until 15 ppm, 50 percent inhibition was at

30 ppm, total inhibition was at 300 ppm. Endotaf had no significant effect until 6 ppm, 50 percent inhibition was at 15 ppm, total inhibition was at 300 ppm.

Adhikary, S.P., Pravata, Dash, Pattnaik, H. (1984) Effect of the carbamate insecticide, Sevin on *Anabaena* sp. and *Westiellopsis prolifica*. *Acta Microbiol. Hung.* 31(4): 335–338.

*Summary:* Effect of the insecticide Sevin [carbaryl]-1-naphthyl methyl carbamate (50 percent wt/vol) was examined on survival, growth and  $N_2$  fixation of two soil-inhabiting, filamentous blue-green algae, *Anabaena* sp. and *W. prolifica*. Lower concentration of the insecticide (10 g/ml) increased survival, growth and  $N_2$  fixation while higher concentrations showed an inhibitory effect.

Ahluwalia, A.S. (1988) Influence of saturn and knockweed on the growth and heterocyst formation in nitrogen-fixing blue-green alga. *Pesticides* (Bombay) 22(10): 43–44.

*Summary:* Saturn and knockweed inhibited the algal growth at relatively higher concentrations. Saturn was more toxic than the knockweed. Lethal doses for saturn and knockweed were recorded to be 20 ppm and 1000 ppm, respectively. There was no significant effect of these herbicides on heterocyst frequency.

Ahmad, M.H., Venkataraman, G.S. (1973) Tolerance of *Aulosira fertilissima* to pesticides. *Curr. Sci.* 42: 108 (Abstract).

*Notes:* *In vitro* experiment showed that all tested herbicides (MCPA, MCPB, Stam F-34) and most of the insecticides (Lindane, Parathion, Endrin, Diazinone, BHC, Sevin) had no adverse effect on algal growth at recommended dose for application (1–2 ppm). Most insecticides had a stimulatory effect on *Aulosira* growth at concentrations lower than 10 ppm. Only BHC reduced algal growth by 50 percent at 1 ppm.

Amla, D.V., Kochhar, V.K. (1982) Physiological and genetic effects on some common phenylalkylureas on nitrogen fixing cyanobacterium *Nostoc muscorum*. In *Proc. Natl. Symp. Biol. Nitrogen Fixation*, IARI, New Delhi p 606 (Abstract).

*Notes:* Herbicides chlorotoluron and diuron were found effective in inducing mutants (pigment deficient, nonfixing, and cyanophage resistant) of *Nostoc muscorum* to 50–100 fold above the background level.

Andreev, V.P., Maslov, Y.I. (1985) Adaptation to diuron of *Anabaena variabilis* and *Cyanidium caldarium* pigment structures. *Fiziol. Biokhim. Kult. Rast.* 17(3): 293–297.

*Summary:* Changes in the absorption spectra of *Anabaena variabilis* and *Cyanidium caldarium* induced by diuron (a herbicide) are compared under conditions of photoautotrophic and photoheterotrophic growing. These changes are shown to be of the adaptive character. Possible adaptation mechanisms are considered.

Andreev, V.P., Maslov, Y.I. (1988) Adaptation to diuron by the cyanobacterium *Anabaena variabilis* Fd. during long periods of cultivation. *Vestn. Leningrad Univ. Biol.* 0(4): 71–75.

*Summary:* Prolonged cultivation of cyanobacterium *Anabaena variabilis* in the presence of sublethal diuron concentrations shows a two-stage character of culture adaptation to herbicide action. The first relatively short-time stage includes physiological adaptation, the main visible characteristics of which is the increased ratio phycobilin/chlorophyll. In the second, more prolonged stage intrapopulation selection of cells with low diuron-sensitivity, having low ratio phycobilin/chlorophyll is observed.

Arvik, J.H., Hyzak, D.L. Zimdahl, R.L. (1973) Effect of metribuzin and two analogs on five species of algae. *Weed Sci.* 21(3): 173–175.

*Summary:* Growth response of five species of soil algae to 4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5(4H) one (metribuzin) and its 6-isopropyl and 6-cyclohexyl analogs were studied in vitro. Species of *Chlorella*, *Chlorococcum*, *Chlamydomonas*, *Anabaena* were exposed to 0.05, 0.1, 0.5 and 1.0 ppm (w/v) of the herbicides in liquid nutrient, while a species of *Schizothrix* was studied at the same levels in soil culture. With one exception, the growth and numbers of all of the algae were significantly reduced by increasing herbicide concentrations. *Anabaena* was not affected by 0.05 ppm of the cyclohexyl analog. No growth was permitted by any of the herbicides at 1.0 ppm. *Chlorella* and *Chlamydomonas* could not grow in the presence of 0.5 ppm of metribuzin or the cyclohexyl analog. Differences in response to the triazinones were noted between species. *Chlamydomonas* was the most sensitive and *Anabaena* and *Chlorella* the most resistant.

Arvik, J.H., Willson, D.L., Darlington, L.C. (1971) Response of soil algae to picloram-2,4-D mixtures. *Weed Sci.* 19(3): 276–278.

*Summary:* The effects of an approximate 1:4 commercial mixture of 4-amino-3,5,6-trichloropicolinic acid (picloram) and (2,4-dichlorophenoxy) acetic acid (2,4-D) on a natural population of soil algae were studied at dosages of 0.28, 0.56, and 1.12 kg/ha of picloram. No change in the composition of the algal flora

was noted over an 18-month period, regardless of dosage. *In vitro* studies indicated that mixtures of picloram and 2,4-D inhibited growth of *Chlorella vulgaris* Beyer. at concentrations above 100 ppm, but concentrations above 250 ppm were needed for growth inhibition of *Cylindrospermum licheniforme* (Bory) Kuetz. or *Chlorococcum* sp. Picloram alone inhibited all three algae at 50 ppm, while 2,4-D produced no inhibitory effects at concentrations less than 400 ppm.

Bahal, M. (1969) The effect of 2,4-Dinitrophenol on heterocyst development in *Anabaena ambigua*. *Phykos* 8: 11–17.

*Summary:* 2,4-dinitrophenol was found to stimulate the development of heterocysts in *Anabaena ambigua*. It was most effective at pH 7.3. The effect produced by DNP could be reversed by ammonium ions.

Batalla, J.A. (1975) Algae in ricefields and use of algicides. [in Spanish] Valencia, Federacion Sindical de Agricultores Arroceros de España. 57 pp. (NS)

*Notes:* Review of algae common in ricefields of Spain and the methods to control them, with emphasis on algicides. The first part of the paper summarizes taxonomy and physiology of ricefield algae. Then detrimental effects of algae and methods to avoid algal growth are presented. Batalla (1975) considers that most detrimental effects of algae are observed during the 30–40 first days of the crop cycle in direct seeded rice and during the first two to three weeks of the crop cycle in transplanted rice. Unicellular algae are usually not considered detrimental except for some mucilaginous epiphytic algae that cover young germinating roots and refrain them to penetrate the soil. Batalla (1975) reports a detrimental effect of *Oscillatoria* sp. when forming a dense membranaceous mat, especially in seedbeds, that refrains gaseous exchanges between soil and water and refrains root penetration into the soil. Filamentous microalgae, especially those of net forming type, are detrimental in direct seeded rice at germination because of competition for light. They also have detrimental mechanical effects on young plants. Macrophytic algae (*Chara* sp.) are not considered to be often detrimental because they develop late in the crop cycle, when the rice plant is high enough not to suffer from mechanical disturbance or competition for light. In 1975, Batalla indicated that there were no algicides specially designed for utilization in ricefields but that most fungicides could be used as algicides. He listed six groups of algicides:

- Copper-based algicides including copper sulphate and copper oxycloiride. Copper sulphate is used at 2–4 ppm/ha. A higher concentration (6 ppm) can be used for direct application on floating algal masses.
- Dithiocarbamates (zineb, maneb, mancozeb, propineb, nabam, metiram)

commercialized as fungicides that can be used as algicides at dosages of 8–20 kg ai/ha.

- “Ftalimidas o derivados imidicos” (Captan, folpet, captafol) are basically cryptogamicides. They can be used as algicides at 3–4 ppm ai. A higher concentration 10–15 ppm was suggested for submerged aquatic macrophytes.
- Naphtoquinone derivatives (Diclone, Chironamid) applied at 3–4 ppm ai. Chironamid was reported to have no significant effect on floodwater invertebrates.
- Organic salts of tin (Fentin) applied at 3–5 kg ai/ha. Their high toxicity to warm blooded organisms refrains their utilization.
- Quaternary salts of ammonium (Dimanin, Hyamine) applied at high concentrations (10–40 ppm) of ai.

Algicides can be applied preventively on the seeds and in the water at the water inlet. For curative applications it is recommended to decrease the water level to about 5 cm before applying the algicide and to avoid irrigation for forty-eight hours. A list of eighteen algicides for use in ricefields is given together with toxicity levels for some freshwater fish.

Batterton, J.C., Bousch, G.M., Matsumura, F. (1971) Growth responses of blue-green algae to aldrin, dieldrin, endrin and their metabolites. *Bull. Environm. Cont. Toxicol.* 6: 589–594. (NS)

*Notes:* In vitro experiment on *Anacystis nidulans* and *Agmenellum quadriculatum*. There was no effect of the tested pesticides at concentrations observed in aquatic environments (< 200 ppb). At higher concentrations a slight decrease in algal growth was observed but no algicidal effect. Results also show that degradation products of this insecticides might be as efficient/detrimental as the parent compounds.

Batterton, J.C., Bousch, G.M., Matsumura, F. (1972) DDT: Inhibition of sodium chloride tolerance by the blue-green alga *Anacystis nidulans*. *Science* 176: 1141–1143.

*Summary:* *Anacystis nidulans*, a freshwater blue-green alga, has been found to tolerate sodium chloride (1 percent by weight) and DDT [1,1,1-trichloro-2,2-bis-(p-chlorophenyl) ethane] (800 parts per billion) separately, but growth was inhibited in the presence of both compounds. This inhibition was reversed by an increased Ca concentration. It is possible that inhibition of (Na<sup>+</sup>, K<sup>+</sup>)-activated ATP-ase by DDT causes this species to lose the ability to tolerate sodium chloride.

Battino-Viterbo, A., Minervini-Ferrante, G., Bisiach, M. (1973) Comparison of activity of some chemicals on *Anabaena* and *Chlorella*. *Riso* 22(4): 327–336.

*Summary:* A series of *in vitro* tests on two algal strains of *Anabaena* and *Chlorella* isolated from Italian ricefields were carried out in order to determine the level of algicidal activity of some chemicals with a low toxicity to warm-blooded animals. Chlortalonil, Dichlorophen, and 2-dichloroacetamide-3-chloro-1,4-naphtoquinone were tested in comparison with triphenyl acetate (Brestan). In order to distinguish between algicidal and algistatic activity, the subculture technique was used. The activity of the various chemicals was characterized with the measure of the trend of cellular multiplication with the spectrophotometric technique. The experimental data were statistically analyzed in order to find the significant differences between the treatments. The trends of growth in function of time and dosages was interpolated with a curvilinear function; the functions were fitted on the experimental data with the multiple regression method. The most effective chemical at low dosage (1–2 ppm) which can be considered as a substitute of Brestan is 2-dichloroacetamide-3-chloro-1,4-naphtoquinone (HOE 2997).

Bednarz, T. (1981) The effect of 2,4-D acid on green and blue-green algae in unialgal and mixed cultures. *Acta Hydrobiol.* 23(2): 173–182.

*Summary:* Low concentrations of 2,4-D usually stimulated the growth of algae. Higher concentrations inhibited or stopped the growth. Chlorococcal green algae were more sensitive than filamentous green and blue-green algae. Two of four sensitive and tolerant species were grown together in mixed cultures treated with 2,4-D. Tolerant species decreased the toxicity of the herbicide to sensitive algae. The protective effect did not appear when *Scenedesmus acutus* was used as the tolerant species.

Bharati, S.G., Angadi, S.B. (1980) Studies on nitrogen fixing blue-green algae: their response to fungicides. Pages 40–42 in *Proceedings of the National Workshop on Algal Systems*. Indian Soc. Biotechnology, IIT/New Delhi 110016, India.

*Summary:* The long- and short-term effects of some commonly used fungicides like Captan, Agallol 3', Dithane-z-78 and Ceresan on algae were studied. It has been established that the nitrogen fixed by any species of blue-green algae is related to the numbers of heterocysts produced by it. Dithan-z-78 in concentrations of 0.5 and 0.1 g/ml produced fixed nitrogen twofold over the control. Ceresan on the other hand affects production of heterocysts and consequently fixes less of nitrogen, this effect is seen in all, more in *Haphalosiphon welwitschii*. An exception to this occurred when the blue-green algae were treated with Agollol 3' and Captan especially on *Anabena azollae* and *H. welwitschii*.

Bharati, S.G., Giryappanavar, B.S. (1986) Effect of two insecticides on the growth of *Calothrix membranacea*, a nitrogen fixing blue-green alga. *J. Karnatak Univ. Sci.* 31: 28–33.

*Summary:* Two insecticides Rogar 30E and Dimecron enhance the growth of *Calothrix membranacea* at particular concentrations, the other concentrations have deleterious effect.

Birmingham, B.C., Colman, B. (1983) Potential phytotoxicity of diquat accumulated by aquatic plants and sediments. *Water Air Soil Pollut.* 19(2): 123–132.

*Summary:* The adsorption and desorption of Reglone A to freshwater algae, *Myriophyllum spicatum* and a soil-sand mixture, singly and in combination was examined to investigate the potential for phytotoxicity of diquat residues in aquatic sediments. The diquat adsorption capacity of the aquatic plants ranged from 0.6–2.4 mg diquat g<sup>-1</sup> dry wt. Of the adsorbed diquat 40–70 percent could be desorbed with 5 M NH<sub>4</sub>Cl. The adsorption capacity of the soil system was ~ 2.5 mg diquat g<sup>-1</sup> dry wt and ~ 35 percent of this diquat could be desorbed. Reglone inhibited the growth of blue-green algae (*Anabaena flos-aquae* and *Anacystis nidulans*) at concentrations > than 0.03 ppm. Eukaryotic algae were less sensitive, growth of *Navicula pelliculosa* was inhibited at concentrations exceeding 0.3 ppm and *Chlorella vulgaris* was unaffected by 3 ppm Reglone. In the presence of soil, growth inhibition by Reglone was eliminated. Reglone was added to a water-soil mixture system at levels up to 334 ppm to simulate chronic usage. *Anabaena flos-aquae* or *Lemna* sp. were used to bioassay the availability of the diquat adsorbed to this soil system. Significant growth inhibition of both bioassay plants was observed in soil treated with 33.4 ppm Reglone and the 334 ppm treatment was lethal. Residual phytotoxicity becomes apparent in this soil system at ~ 7 percent of the diquat adsorption capacity. The Reglone adsorption-desorption isotherm of a natural, organic lake sediment was measured to predict the number of Reglone treatments at the recommended application rate before residual phytotoxicity would become apparent.

Bisiach, M. (1972a) Laboratory algicidal screening for the control of algae in rice. *Riso* 21(1): 43–58 (Summary in Italian).

*Notes:* Filamentous BGA are quoted as possible detrimental algae in ricefields. However the *in vitro* tests of algicidal effect of Fentin acetate, Benzuride, Captafol, HOE 2997, Folpet, and MnO<sub>4</sub>K are performed on *Spirogyra* sp., *Oedogonium* sp., and *Hydrodictyon reticulatum*, which are considered as the algae most detrimental to rice. Efficient concentrations range from 1 to 8 ppm however, the authors indicate that efficiency is higher *in vitro* than *in situ*.

Bisiach, M. (1972b) Preliminary laboratory tests for the control of algae in ricefields. *Riv. Parol. Veg. Ser.* 4, 8(2): 159–181.

*Summary:* A method of preliminary *in vitro* test to determine algicidal and algistatic activity of chemical compounds against the most common algal forms infesting ricefields is here described. Against *Spirogyra* sp., *Oedogonium* sp., and *Hydrodictyon reticulatum*, the following chemicals have been tested: Benzuride, Captafol, HOE 2997, Folpet and  $\text{KMnO}_4$  at the concentrations 0.5–1–2–4–8 ppm. All the chemicals except Benzuride showed a marked algicidal activity. Particularly HOE 2997 (2, dichloroacetamido-3, chloro, 1,4 naphthoquinone) has a complete algicidal activity at 1 ppm against *Oedogonium* sp. and *Hydrodictyon reticulatum* and at 2–4 ppm against *Spirogyra*. The naphthoquinone derivative is not phytotoxic for rice and on account of its very high DL50 (11,700–15,000 mg/kg) opens new interesting perspectives for the control of algae in ricefields.

Bongale, U.D. (1985) On the response of spore germination and growth of three nitrogen-fixing cyanobacteria, isolated from soils, to pesticides: An assessment as bioindicators. *Symp. Biomonitoring State Environ.* 190–196. (NS)

*Notes:* *In vitro* experiment testing the effect of Aldrex-30, Monochrotophos-36, Rogor-30, BHC-50, Dithane M-45, Deltan-75 and Phorate-10 on the germination of spores of *Nostoc microscopium*, *Hapalosiphon welwitschii*, and *H. confervaceus*. Effect of pesticides is estimated through visual observations at fifteen and twenty-five days and fresh weight measurement at 65 days.

Braginskii, L.P., Beskaravainaya, V.D., Shcherban, E.P. (1979) Responses of freshwater phytoplankton and zooplankton to pesticides. *Izv. Akad. Nauk. SSSR Ser. Biol.* 0(4): 599–606.

*Summary:* Pesticides, with regard to their concentration level, may suppress or activate planktonic organisms. In both cases pesticide effects are revealed at temperatures not lower than 17°C. Phytoplankton [*Aphanizomenon* and *Anabaena*] was suppressed by pesticides at concentrations from 1–10 mg/l, but some susceptible components of zooplankton [*Microcystis aeruginosa*] were suppressed at concentrations from  $10^{-1}$  to  $10^{-2}$  mg/l, the effect being chronic in rapidly succeeding generations. Phytoplankton possess buffer properties with respect to pesticide resistance. Variations in the structure of biocenoses are mainly related to changes in dominant forms.

Butler, G.L. (1977) Algae and pesticides, *Residue Reviews* 66: 19–62.



*Summary:* Although the algae are generally not the intended recipients of most pesticide applications, they comprise an important segment of the ecosystem which may be affected. As might be expected, the algae are highly susceptible to herbicides (e.g., triazines and ureas) but they are also inhibited by insecticides and fungicides (e.g., organochlorines and quinones). Much of the information on the effect of herbicides on algae has come indirectly from the study of herbicidal mode-of-action. The number of studies on the interaction of pesticides and algae are on the increase but only a small number of the hundreds of commonly used pesticides have been tested. In order to increase our understanding of the effects of various pesticides on the growth of algae, there are several areas in which investigators will need to concentrate their efforts. The effects of combinations of pesticides with other pesticides, with heavy metals, or with organic compounds on artificially generated communities or natural communities of algae or algae with other aquatic microorganisms will need to be studied. Because most investigations using marine algae have been limited to the phytoplankton, future work should include the study of pesticide effects on the macroscopic marine algae. Also, emphasis needs to be directed towards stages in the reproductive cycle since gametes may be more susceptible than the purely metabolic, vegetative plant body.

Cameron, H.J., Julian, G.R. 1984 The effects of four commonly used fungicides on the growth of cyanobacteria, *Plant Soil* 78: 409–415.

*Summary:* Four fungicides used commonly in agriculture are shown to be inhibitory to the axenic cultures of several species of cyanobacteria. Thus, fungicides may limit the beneficial effect of these microorganisms on soil nutrition.

Chaudhari, P.R., Jayangouder, I., Krishnamoorthi, K.P. (1989) Response of some common freshwater algae to DDT applications. *Proc. Indian Acad. Sci. Plant Sci.* 99(3): 279–286.

*Summary:* Growth pattern of three common freshwater algae *Chlorella*, *Scenedesmus*, and *Spirulina* was studied under the influence of organochlorine pesticide DDT, under laboratory conditions. *Scenedesmus* was found to be sensitive to DDT doses and growth was inhibited maximally up to 42 percent after 96 h at 5 ppm concentration. This alga shows phenotypic variations also in its colony structure at 3 ppm concentration. *Chlorella* and *Spirulina* are found to be highly tolerant and no growth inhibition is recorded at all doses of DDT. On the other hand, growth of these algae is promoted over that of control under the influence of DDT.

Chen Pei Chung. (1986) Effect of herbicides on growth and photosynthesis in *Anabaena* CH<sub>1</sub> and CH<sub>2</sub>. *Proc. Nat. Coun. Rep. China Part B Life Sci.* 10(3): 151–156.

*Summary:* At herbicides butachlor or bromacil concentrations even as high as 100 ppm, growth and physiological activities of *Anabaena* CH<sub>2</sub> cells were not significantly altered. Benthioncarb inhibited cellular chlorophyll content, nitrogen fixation, photosynthetic and respiratory activities of CH<sub>2</sub> seemed to proceed simultaneously. The growth and physiological activities of *Anabaena* CH<sub>3</sub> cells would also be repressed by benthioncarb. Butachlor inhibited nitrogen fixation prior to photosynthetic activity. Bromacil would somewhat interfere in its growth and physiological activities. Photosystem I activity of *Anabaena* CH<sub>2</sub> and CH<sub>3</sub> would be slightly inhibited by 6 ppm benthioncarb or 100 ppm bromacil, PS II activity was not interfered with contrarily. Herbicide butachlor (100 ppm) would inhibit 45 percent of PS I activity of CH<sub>2</sub>, but slightly affect PS I activity of CH<sub>3</sub>, and PS II activity of CH<sub>2</sub>. Photosystem II activity of CH<sub>3</sub> would not be influenced by 100 ppm butachlor.

Chinnaswamy, R., Patel, R.J. (1983) Effect of pesticide mixtures on the blue-green alga *Anabaena flos-aquae*. *Microbios Lett.* 24(95/96): 141–144.

*Summary:* The effect of the herbicide basalin and insecticides benhexol and thiodan on the blue-green alga, *A. flos-aquae*, individually and in combination with the herbicide fernoxone, was studied. Benhexol and thiodan suppressed the growth promoting activity of fernoxone whereas basalin did not affect such activity. Inhibitory effects were also observed.

Chinnaswamy, R., Patel, R.J. (1984) Blue-green algae and pesticides. *Pesticides* 18(9): 5–11. (NC)

Chinnaswamy, R., Patel, R.J. (1986) Detoxication of herbicides by blue-green algae. *Indian J. Ecol.* 13(1): 5–9.

*Summary:* Two nitrogen fixing blue-green algae viz. *Anabaena flos-aquae* and *Nostoc* sp. were grown in media containing the herbicides basalin and fernoxone. *Sorghum vulgare* and *Lepidium sativum* were employed as test species to detect the detoxicating ability of the algae. Algal culture filtrates and herbicide solutions were used for seed germination tests. The usefulness of bioassays to study detoxification of herbicides is discussed.

Cooper, S.L., Wingfield, G.I., Lawley, R., Greaves, M.P. (1978) Miniaturized methods of testing the toxicity of pesticides to microorganisms. *Weed Res.* 18(2): 105–108.

*Summary:* A miniaturized method of determining the toxicity of pesticides to large numbers of soil microorganisms is described. Bacteria, actinomycetes, yeasts, fungi and algae can be used as test organisms. A modification of the method allows determination of minimum inhibitory concentrations of pesticides to specific microorganisms. Some results obtained with herbicides are presented.

Couture, P., Visser, S.A., van Coillie, R., Blake, C. (1985) Algal bioassays: their significance in monitoring water quality with respect to nutrients and toxicants. *Schweiz. Z. Hydrol.* 47(2): 128–158.

*Summary:* The review focuses on the use of primary producers as a biological tool for evaluating the impact of damage by human activity (eutrophication toxicity) on the aquatic environment. Studies are discussed following a reductionist approach by using algal bioassays (*Selenastrum capricornutum*). Variations of algal growth potential (AGP) within watersheds shows the impacts of human activities such as agriculture and urbanization on water quality. The study of variation of the AGP in time allowed the investigation of the effect of abiotic (temperature flow rate) and biotic factors (indigenous primary production) on the concentration of nutrients potentially available to phytoplankton. Seasonal changes of the AGP have further shown the impact of non-point (runoff) or point source (sewage effluents) on the aquatic system. A staggered relationship was observed between AGP values and chlorophyll-a content of indigenous phytoplankton. Values obtained in the laboratory by means of this type of approach would therefore appear to be transferable to natural systems. *S. cupricornutum* was also used to identify toxic characteristics of substances in pure form or used in formulations and effluents released into the environment. It was shown that the use of bioassays should use care when evaluating results from tests requiring pretreatment such as storage autoclaving and filtration. Cautious interpretation is also recommended in order to distinguish between effects of growth-limiting essential elements and the presence of toxic substances. In general it appears from this review that the AGP provides helpful information for a sound management of the aquatic environment.

Cullimore, D.R., McCann, A.E. (1977) Influence of four herbicides on the algal flora of a prairie soil. *Plant Soil* 46: 499–510.

*Summary:* Four herbicides (2,4-D, trifluralin, MCPA and TCA) were applied at two concentration levels to isolated cores of a grassland loam soil. After herbicide contact times of 1, 5, and 20 days, samples were taken and the algal population estimated both quantitatively and qualitatively using two selective mineral salts media. Thirty one genera of algae were identified as occurring in

the soil. Of these, *Chlamydomonas*, *Chlorococcum*, *Phormidium*, *Palmella*, and *Ulothrix* proved to be so sensitive to the four herbicides that they were rarely isolated from the cores after treatment. Other algal genera were found to be less sensitive, and the theoretical percentile sensitivity of fifteen genera was calculated. *Chlorella*, *Lyngbya*, *Nostoc*, and *Hantzschia* were found to be the most resistant algae, having percentile sensitivity to all four herbicides of less than 50 percent. Some algal genera varied in their sensitivity to each of the herbicides. *Scytonema* was sensitive to all of the herbicides except, 2,4-D, while *Tolyporhrix* showed a greater tolerance to MCPA. In the top cm of the soil, the reduction in cell numbers experienced by many algal genera after herbicide treatment was offset by an increase in the population of *Chlorella*. *Stichococcus*, *Oscillatoria*, and *Spongiochloris* all exhibited the ability to recover rapidly after a reduction in cell numbers resulting from the application of one of the herbicides. An overall reduction in cell numbers was noted for the algae growing preferentially on a nitrogen-free medium (i.e. potential nitrogen-fixers).

Dar, G.H., Zargar, M.Y. (1988) Effect of cuproxol and carbendazim on *Gloeocapsa*. *Ind. J. Ecol.* 15: 2. (NC)

Das, B. (1977) Effect of herbicides and pesticides on the freshwater blue green algae, Ph.D. dissertation, Utkal University, Vani Vihar, India. (NC)

Das, B., Singh, P.K. (1977a) Detoxication of the pesticide benzenehexachloride by blue-green algae. *Microbios Lett.* 4: 99–102.

*Summary:* The nitrogen fixing blue-green algae *Anabaenosis raciborskii* and *Anabaena aphanizomenoides* were employed in detoxicating the toxic effect of a pesticide BHC in nutrient medium. A gradual loss in the toxicity of BHC was noticed when repeated inoculation and removal of the algae was ensured. Therefore, the pesticide could be detoxicated by repeated growing and removing blue-green algae from the pesticide containing medium.

Das, B., Singh, P.K. (1977b) Effect of 2,4-dichlorophenoxy acetic acid on growth and nitrogen fixation of blue-green alga *Anabaenopsis raciborskii*. *Arch. Environ. Contam. Toxicol.* 5: 437–445.

*Summary:* Sodium salt of 2,4-dichlorophenoxyacetic acid (80 percent active ingredient), commonly applied for the control of aquatic weeds, was used to observe its effect on the growth and nitrogen fixation of a heterocystous bloom forming blue-green alga *Anabaenopsis raciborskii*. A concentration of 10 g/ml of 2,4-D showed stimulation of growth and nitrogen fixation and these were almost unaffected in presence of its 100 g/ml in the medium. The alga could

tolerate up to 800 g/ml in liquid culture media with and without nitrate nitrogen and up to 90 g/ml on to agar plates. Nitrogen fixation was inhibited in presence of its higher concentrations.

Das, B., Singh, P.K. (1978a) Mutagenicity of pesticides in blue-green algae. *Microbios Lett.* 5: 103–107.

*Summary:* An attempt was made to screen the probable mutagenic action of an insecticide hexachlorocyclohexane (BHC) and a weedicide 2,4-dichlorophenoxy acetic acid (2,4-D) on nitrogen-fixing blue-green algae *Anabaenopsis raciborskii*, *Anabaena aphanizomenoides*, *Anabaena spiroides*, and on a non-nitrogen-fixing alga *Microcystis flos-aquae*. Three classes of morphological mutants, i.e. gas-vacuole-less (GV-), long filament forms (L forms) and straight filament forming (St forms) could be easily detected in untreated (spontaneously) and pesticide treated cultures. The slight increase in mutation frequencies was noticed after treatment with BHC, but 2,4-D treated cultures did not show any increase. The results suggested that BHC is mutagenically weak for blue-green algae whereas 2,4-D is non-mutagenic.

Das, B., Singh, P.K. (1978b) Pesticide (hexachlorocyclohexane) inhibition of growth and nitrogen fixation in blue-green algae *Anabaenopsis raciborskii* and *Anabaena aphanizomenoides*. *Zeit. Allg. Mikrobiol.* 18(3): 161–167.

*Summary:* The effects of the pesticide hexachlorocyclohexane (HCH) on the  $N_2$  fixing blue-green algae *Anabaenopsis raciborskii* and *Anabaena aphanizomenoides* commonly found as blooms in fish ponds were studied. These algae were very sensitive to HCH, and a distinct decrease in growth rate was observed on prolonged incubation. Lower concentrations (10 g/ml) were algistatic and higher concentrations (60 g/ml) were algicidal. The inhibition of  $N_2$  fixation indicated that the presence of HCH might affect overall nitrogen economy of inland waters.

Das, B., Singh, P.K. (1979) Relative tolerance of a bloom forming blue-green alga *Microcystis flos-aquae* (Witt.) Kirchner to pesticides. *Nova Hedvigia* 63: 161–172.

*Summary:* The effects of herbicide 2,4 dichlorophenoxy acetic acid (2,4-D) and a pesticide benzene hexachloride (BHC) were studied on the growth of a bloom forming blue-green alga *Microcystis flos-aquae* commonly found in ponds. At the level of 10–100 g/ml of 2,4-D, growth of alga was stimulated but higher concentrations had depressing effects. The concentration of 100–1,000 g/ml were algistatic and 15,000 g/ml was algicidal. The concentration of 10 g/ml of BHC

did not affect the growth significantly whereas its higher concentrations showed inhibitory effects. The concentrations of 10–80g/ml were algistatic and 100 g/ml was algicidal.

Das, S.S. (1976) Algal weeds and their chemical control: A review. *Indian J. Plant. Prot.* 4(2): 201–208,

*Summary:* Algal weeds *Chara* sp. and *Nitella* sp. are particularly responsible for considerable loss of paddy in West Bengal in low lying areas near the sea. Algal weeds are widely distributed throughout India except in dry desert areas of Rajasthan. Out of several algicides tried, copper sulphate, roccal, ferbam, dichlone, fentin acetate, nitrofen, zineb, tetrachloroisophthalonitrile, simazine, fentin hydroxide, 2,4, disodium ethylene bisdithiocarbamate (93 percent), Hoe 2873 (F), diquat, diquat dibromide, tri-butyl tinchloride with solubilizer, bis-(tri-n-butyltin) oxide with solubilizer and silver methane-arionate, hydrothol 191, simazine + prometryne W.P., diruron + - TCA, fenuron + - TCA, monuron + - TCA were effective in controlling various algae. Dichlobenil has proved to be a very promising preemergence herbicide for control of *Cladophora*, *Pithophora* and *Chara* sp. For controlling filamentous green algae *Oedogonium* sp. and *Rhizoctonium* sp. di-(N, N-dimethylcocoamine) and mono (N, N-dimethyl alkylamine) formulation of endothal proved the most effective.

DaSilva, E.J., Henriksson, L.E., Henriksoon, E. (1973) Effects of pesticides on asymbiotic and symbiotic nitrogen-fixing blue-green algae. Abstract (No. 14, p. 3), VI. International Conference in Global Impacts of Applied Microbiology. Sao Paulo, Brazil, July 1983.

*Abstract:* The effects of eight widely hitherto used pesticides comprised of one insecticide and seven herbicides were studied in five concs. (5–250ppm) on the nitrogen-fixing capacities of nine asymbiotic cyanophycean species from the genera *Aulosira*, *Anabaena*, *Calothrix*, *Chlorogloea*, *Cylindrospermum*, *Nostoc*, and *Westiellopsis*. The phycobiont of the lichen *Collema tenax* was also used in the analysis. Whereas a stimulatory effect was observed in nitrogen-fixation in most forms a general pattern of gradual decline occurred at the end of a five-hour period. In general, phenylureas, phenoxyacetic acid and an organophosphorus compound were stimulatory initially in comparison to amitrole and the bipyridylum quarternary salts which had an adverse effect. In these short-term experiments a pronounced depression of cessation of nitrogen-fixation occurred in *Calothrix elenkinii* and *Cylindrospermum muscicola* with the quarternary salts. In long-term experiments following an initial static period of activity, most species recovered from their corresponding period of decline in short-term

experiments. The substituted ureas, monuron and linuron exhibited stimulatory effects in four forms.

DaSilva, E.J., Henriksson, L.E., Henriksson, E. (1974) Effect of pesticides on nitrogen fixation by blue-green algae. *Rev. Microbiol.* (S. Paulo) 5(4): 73–74.

*Summary:* Effect of pesticides amitrole and its derivative, monuron, linuron, digust, paraquat, MCPA, and of insecticide malathion on the abilities of nitrogen-fixation by green-algae *Anabaena cylindrica*, *Aulosira* sp., *Calothrix elenkenii*, *Chlorogloea fritschii*, *Cylindrospermum muscicola*, *Nostoc muscorum*, *Tolypothrix tenuis*, *Westiellopsis* sp., and the phycobiont, *Nostoc* sp.

DaSilva, E.J., Henriksson, L.E., Henriksson, E. (1975) Effect of pesticides on blue-green algae and nitrogen fixation. *Arch. Environ. Contam. Toxicol.* 3: 193–204.

*Summary:* The effects of the pesticides, amitrol, a derivative of amitrol (viz. 3–5-diamino-1,2,4-triazole), diquat, paraquat, linuron, MCPA, malathion, and monutron, were studied on the N<sub>2</sub>-fixing algae, *Anabaena cylindrica*, *Aulosira* sp., *Calothrix elenkenii*, *Chlorogloea fritschii*, *Cylindrospermum muscicola*, *Nostoc* sp. from *Collema tenax*, *Nostoc muscorum*, *Tolypothrix tenuis*, and *Westiellopsis* sp. In general, two types of response were discernible; an initial period of depression succeeded by an increased activity and an initial period of depression followed by a distinct decrease on prolonged incubation. The results indicate that some pesticidal compounds can severely limit the nitrogen-fixing capacities of blue-green algae, thereby affecting the overall nitrogen economy of soils in general.

Dhanarai, P.S., Kumar, S., Lal, R. (1989) Bioconcentration and metabolism of aldrin and phorate by the blue-green algae *Anabaena* (ARM 310) and *Aulosira fertilissima* (ARM 68). *Agric. Ecosyst. Environ.* 25(2/3): 187–194.

*Summary:* *Anabaena* sp. and *Aulosira fertilissima* showed marked ability to bioconcentrate aldrin and phorate from culture medium. Uptake was directly related to the insecticide concentration in the medium and was inversely related to the water solubility of the insecticides. Bioconcentration of aldrin in *Anabaena* sp. and *A. fertilissima* ranged from 3.9 to 247.5 g/g, respectively. Maximum concentration of aldrin in the blue-green algae was reached after 8–16h and that of phorate after 16–32h. Aldrin was metabolized to dieldrin by both blue-green algae but no metabolism was noticed in the case of phorate.

Dierksheide, W.C., Pfister, R.M. (1973) Uptake of dieldrin by two blue-green algae. *Abst. Ann. Meet. Amer. Soc. Microbiol.* p. 32 (Nc)

Dooley, F., Houghton, J.A. (1974) The nitrogen fixing capabilities and the occurrence of blue-green algae in peat soils. *Br. Phycol. J.* 8: 289. (NC)

Dunigan, E.P., Hill, V. (1978) Studies on the use of chemicals to control algal surface blooms in rice floodwaters. *Louisiana Agric. Exp. Sta. Dept. Agron. Reports on projects for 1977*. Baton Rouge, La. 153–156. See next reference for summary.

Dunigan, E.P., Hutchinson, R.L., Hill, V. (1979) Can algal blooms be controlled in ricefield floodwaters? *Louisiana Agric.* 32(3): 3, 15.

*Summary:* The effects of the three chemicals on algal growth, rice growth, yield, and Cu concentration in the rough rice seed from May through July 1977, was studied. Algal blooms were not a big problem in the summer of 1977; however, the data indicate that Bluestone (copper sulfate) and the copper-chelates gave significantly lower value for control of algal formation without adverse effects on vegetative rice growth or seed yield. Copper concentration in seed from the treated plots were slightly in excess of those in seed from the control plots, but none of the values was considered high. Because Bluestone was the only material that had an EPA clearance, it was used in small outfield plots at three farms near Abbeville, Chataignier, Crowley during the summer of 1977. These fields were selected because each had a previous history of prolific algal blooms during the early growing season. Although algal blooms were not heavy in 1977, the data did indicate that the early application of Bluestone before the first sign of a bloom aided in controlling the algal formation. No adverse effects on rice growth were noted, nor did the Bluestone applications cause any significant increases in the copper concentration in the grain. In summary, several chemicals were found to control algal blooms in ricefield floodwater. However, until further labeling is approved, Bluestone is the only algicide that can be used safely in ricefields. Test results indicated that if it was applied before a bloom started, or at the first sign of a bloom, it generally gave adequate control of the algae.

El-Haddad, M.E. (1984) Changes in metabolic activities of *Nostoc muscorum* and *Anabaena oryzae* in response to herbicide application. 1. Effect of molinate and benzthiocarb. Pages 277–285 in *Soil biology and conservation of the biosphere*, J. Szegi (ed.). Budapest: Akademiai Kiado. 2 v.

*Summary:* Two thiocarbamate herbicides, namely molinate /S-ethyl hexahydro-1 M-azepine-1 -carbothionate/ and benzthiocarb /S-/4—chlorobenzyl/-NN-diethyl thiocarbamate/ were tested for their effect on the growth and metabolic activities of *Nostoc muscorum* and *Anabaena oryzae*. Results indicated that molinate exerted



a stimulatory effect on growth yield,  $N_2$ -fixation, and chlorophyll a content of both algae, while in the presence of benzthiocarb, all these parameters markedly decreased. The changes of magnesium, phosphorus and sugar uptake, as well as dehydrogenase activity of both algae, in response to herbicide application were also followed.

El-Sawy, M., Mahmoud, S.A.Z., EL-Haddad, M.E., Mashhour, W.A., Salem, K.G. (1984) Effect of different herbicides on nitrogen fixation by blue-green algae in paddy soil. Pages 297–306 in *Soil biology and conservation of the biosphere*, J. Szegi (ed.). Budapest: Akademiai Kiado. 2 v.

*Summary:* Algal inoculation with *Nostoc muscorum* and *Anabaena oryzae* in paddy soils, as affected by the herbicides molinate, benzthiocarb, fluorodifen and propanyl was investigated. Different types of soils were used in this study. The response of algal inoculation in the presence of the mentioned herbicides was indexed by measuring plant height, number of leaves, shoot dry weight, total nitrogen content of shoot and percentage of soil nitrogen. Results revealed that there is no risk in the application of herbicides under study on the activity of the inoculated algae.

EINawawy, AS., El Fadl, M.A., Nada, M.M. (1962) Economical studies on algae in Egypt. I. Effect of new isothiuronium derivatives of arylmercaptoalkane carboxylic acids on the paddy soil flora of algae in Egypt. *J. Soil Sci. UAR* 2(1): 3–14.

*Summary:* The algicidal properties of the Na salt and six s-alkylisothiuronium salts of one of the arylmercaptoacetic acid were studied in a glucose-salts medium. The inoculant was a mixed algal culture which had been obtained from ricefields in Egypt. The s-alkylisothiuronium compounds at a concentration of 0.5 g anionni destroyed all algae. Some were effective at lower concentrations. Reinoculation after 15 days revealed the persistence of all or some of the algicidal properties. The Na salt was less toxic to algae. All the compounds, at lower concentration, had a selective action, unicellular green algae being more resistant than filamentous forms.

Entzeroth, M., Mead, D.J., Patterson, M.L., Moore, R.E. (1985) A herbicidal fatty acid produced by *Lyngbya aestuarii*. *Phytochemistry* (OXF) 24(12): 2875–2876.

*Summary:* A herbicidal component isolated from ethanolic extracts of *Lyngbya aestuarii* was identified as 2,5-dimethyldodecanoic acid. It inhibited the growth of *Lemna minor* at concentrations higher than 200 ng/ml. Growth inhibition was strongly pH dependent.

Fitzgerald, G.P., Gerloff, G.C., Skoog, F. (1952) Studies on chemicals with selective toxicity to blue-green algae. *Sewage Ind. Wastes*. 24: 888. (NC)

Fitzgerald, G.P., Skoog, F. (1954) Control of blue-green algae blooms with 2,3-dichloro naphtho-quinone. *Sewage Ind. Wastes* 26: 1136. (NC)

Friedberg, D., Seijffers, J. (1988) Sulfonyleurea-resistant mutants and natural tolerance of cyanobacteria. *Arch. Microbiol.* 150(3): 278–281.

*Summary:* The herbicide sulfometuron methyl (SM) inhibited the growth of the cyanobacterium *Synechococcus* sp. PCC7942, but not of *Synechocystis* sp. PCC6714. The inhibitory effect was alleviated by the simultaneous addition of valine, leucine and isoleucine. SM resistant mutants were isolated from *Synechococcus* 7942, two types of which were further analyzed. In these mutants, SM3/20 and SM2/32, the activity of acetolactate synthase (ALS)- a key enzyme in the biosynthesis of branched-chain amino acids-appeared 2600- and 300-fold, respectively, more resistant to SM than that of their wild type. Strain SM2/32 also exhibited a low level of ALS activity. Although the growth of the latter mutant was extremely inhibited by valine, the sensitivity of its ALS activity to feed-back inhibition by the amino acid was unaltered. At high concentrations valine inhibited growth of the wild type strains and of the mutant SM3/20. Isoleucine alleviated the valine-induced growth inhibition. Unlike that of *Synechococcus* 7942, the ALS activity of *Synechocystis* was found to tolerate high concentrations (100-fold) of the herbicide. The study confirms that the SM mutations are correlated with a cyanobacterial *ilv* gene.

Fritz-Sheridan, R.P. (1982) Impact of the herbicide magnacide-H (2-propenal) on algae. *Bull. Environm. Contam. Toxicol.* 28: 245–249(NS).

*Notes:* *In vitro* tests on *Enteromorpha intestinalis*, *Cladophora glomerata*, and *Anabaena* sp. with concentrations ranging from 10 ppb to 10 ppm. Significant decrease in photosynthetic activity was observed with the three strains at concentrations higher than 70 ppm.

Magnacide is an herbicide used as algicide in freshwaters and irrigation canals.

Gadkari, D. (1987) Influence of the photosynthesis-inhibiting herbicides Goltix and Sencor on growth and nitrogenase activity of *Anabaena cylindrica* and *Nostoc muscorum*. *Biol. Fertil. Soils* 3(3): 171–178.

*Summary:* The influence of the photosynthesis-inhibiting herbicides Goltix and Sencor on growth and nitrogenase activity of *Anabaena cylindrica* and *Nostoc muscorum* was studied. The cyanobacteria were grown under N<sub>2</sub>-fixing

photoautotrophic conditions. *A. cylindrica* was entirely inhibited even in the presence of low field concentrations (Sencor 10 ppm, Goltix 50 ppm). In contrast, Goltix (50 ppm and 100 ppm) and Sencor (10 ppm, 20 ppm, 50 ppm and 100 ppm) did not exert an inhibitory influence on growth and nitrogenase activity of *N. muscorum*. In the presence of normal field rates of the studied herbicides increased light intensities during incubation had no detrimental effect on *N. muscorum*. Only at 20 W/m<sup>2</sup> light intensity did the higher concentrations of Sencor (50 ppm and 100 ppm) cause partial inhibition for the first 10–12 days, which was compensated during subsequent incubation. The delayed inhibitory effects caused by higher concentrations of Goltix (200 ppm and 500 ppm) are supposed to be due to degradation product(s). In the natural environment other species of cyanobacteria may occur which are able to tolerate photosynthesis-inhibiting herbicides.

Gadkari, D. (1988a) Assessment of the effects of the photosynthesis-inhibiting herbicides diuron, DCMU, metamiltron and metribuzin on growth and nitrogenase activity of *Nostoc muscorum* and a new cyanobacterial isolate, strain G4. *Biol. Fertil. Soils* 6(1): 50–54.

*Summary:* The influence of the photosynthesis-inhibiting herbicides Diuron, DCMU, metamiltron, and metribuzin in growth and nitrogenase activity of *Nostoc muscorum* and a new cyanobacterial isolate, strain G4, was studied. The experiments were performed under N<sub>2</sub>-fixing photoautotrophic conditions. Both cyanobacteria showed a high degree of tolerance towards the herbicides tested. In the presence of metamiltron (35, 70, and 140 ppm) and metribuzin (7, 14, 35, and 70 ppm) strain G4 proliferated as well as the control culture. Metamiltron and metribuzin had no influence on the nitrogenase synthesis of strain G4 and *N. muscorum*. When treated with 1 uM DCMU, strain G4 and *N. muscorum* showed partial inhibition for the first few days, but entirely recovered during succeeding incubation. In the presence of 10 ppm Diuron, *N. muscorum* and strain G4, compared to the control, showed 30 percent and 80 percent nitrogenase activity, respectively.

Gadkari, D. (1988b) Effect of some photosynthesis-inhibiting herbicides on growth and nitrogenase activity of a new isolate of cyanobacteria, *Nostoc* G3. *J. Basic. Microbiol.* 28(7): 419–426.

*Summary:* The effect of the photosynthesis-inhibiting herbicides Goltix, Sencor, Tycor, Arelon, DCMU, paraquat and atrazine on growth and nitrogenase activity of a new isolate of cyanobacteria, *Nostoc* G3 was studied. *Nostoc* G3 was cultivated under N<sub>2</sub>-fixing photoautotrophic conditions. The used herbicide concentrations were in the range or recommended field rates. In the presence of

Goltix (50 mg/l and 100 mg/l), Arelon (15 mg/l and 20 mg/l) and DCMU (1  $\mu$ M) the growth and nitrogenase activity of *Nostoc* G3 was almost completely inhibited. The most severe inhibitory effect was observed in the presence of paraquat. Even 1 h treatment of 1 mg/l paraquat caused a total inhibition of growth for 4 weeks. In contrast, the herbicides Sencor (10 mg/l and 20 mg/l) and Tycor (10 mg/l and 50 mg/l) did not cause inhibition of growth and nitrogenase activity. In the presence of atrazine (1 mg/l and 2 mg/l) the nitrogenase activity and the growth were partially inhibited. The results obtained in this study show that cyanobacteria occurring in natural environments are resistant against some of the photosynthesis-inhibiting herbicides.

Gangawane, L.V. (1979). Tolerance of Thimet by nitrogen fixing blue-green algae. *Pesticides* 13: 33–44.

*Summary:* Thimet 10 G was not deleterious to *Westiellopsis* sp., *Aulosira* sp., *Tolypothrix* sp. and *Calothrix* sp. at the concentration of 1000, 500 and 300 ppm a.i. respectively. *Nostoc* sp., however, did not tolerate even 1 ppm of Thimet.

Gangawane, L.V. (1980) Tolerance of N-fixing blue-green algae to Brassicol, Bavistin and Fytolan. *J. Indian Bot. Soc.* 59: 157–160.

*Summary:* Tolerance of five nitrogen fixing algae (*Westiellopsis* sp., *Aulosira* sp. *Nostoc* sp., *Tolypothrix* sp. and *Calothrix* sp.) to three fungicides (Brassicol, Bavistin and Fytolan) was studied. All species could tolerate fungicides at different concentrations. Higher concentration (500–1,000 ppm) of Brassicol were tolerated than Bavistin and Fytolan. *Calothrix* sp. was complete sensitive to Bavistin while the growth of *Nostoc* sp., and *Tolypothrix* sp. was stimulated due to Bavistin at 100 and 50 ppm respectively. *Tolypothrix* sp. and *Aulosira* sp. were not affected in the presence of Brassicol and Fytolan. Germination of the seeds of rice varieties Suhasini, Surya and Satya was not affected by these fungicides except in few concentrations where only 5–10 percent reduction in the germination was observed. However, Bavistin stimulated root growth of all varieties and shoot length of Satya was promoted by all the fungicides.

Gangawane, L.V., Chaporkar, C.B., Khalil, K. (1982) Effect of fungicides on the production of ascorbic acid and nitrogen fixation by *Nostoc* sp. and *Tolypothrix tenuis*. Pages 670–671 in *Proceedings of the National Symposium on Biological Nitrogen Fixation*, IARI, New Delhi. (Abstract)

*Notes:* Effect of captan, MBC, zineb, quintozene, copperoxychloride, and thiram on the production of ascorbic acid and nitrogen fixation by the two species.

Gangawane, L.V., Deshpande, J. (1981) Effect of the nematicide algae *Mastigocladus laminosus* and *Aulosira fertilissima*. *Pestology* 5: 31. (NC)

Gangawane, L.V., Kulkarni, L. (1979) Tolerance of certain fungicides by nitrogen fixing blue-green algae and their side effects on rice cultivars. *Pesticides* 13(5): 37–38.

*Summary:* Tolerance limits of *Westiellopsis* sp., *Aulosira* sp., *Nostoc* sp., *Tolypothrix* sp. and *Calothrix* sp. to Topsin-M, Rovral, Thiram and Duter were studied. There was variation in the tolerance limits of these microorganisms to the fungicides. All the organisms tolerated Topsin-M and Rovral but were complete sensitive to Duter even at 1 ppm. Thiram was tolerated by *Nostoc* sp. and *Tolypothrix* sp. only. The growth of *Westiellopsis* sp. was much more affected than in others in the presence of fungicides. The growth was not affected in *Aulosira* sp. and *Calothrix* sp. There was no considerable effect of Topsin-M and Thiram on rice cultivars Suhasini and Satya. Rovral increased shoot length of Satya.

Gangawane, L.V., Saler, R.S. (1979) Tolerance of certain fungicides by nitrogen-fixing blue-green algae. *Curr. Sci.* 48(7): 306–308. (NS)

*Notes:* MBC, Difolatan and Hexacap were tested on five strains of N<sub>2</sub>-fixing BGA. Except for the inhibition of *Westiellopsis prolifica* by MBC, all the other fungicide x BGA combinations showed final tolerant concentrations ranging from 100 to 1000 ppm.

Gangawane, L.V., Saler, R.S., Kulkarni, L. (1980) Effect of pesticides on growth and heterocyst formation in *Nostoc* sp. *Marathawada Univ. J.* 19: 3. (NC)

Gapochka, L.D., Veselago, L.A., Levina, M.Z. (1987) Adaptive reactions of algae populations to the action of toxic substances. *Biol. Nauki.* (Mosc) 0(3): 74–80.

*Summary:* The adaptive reactions of alga populations to the toxic effect have been investigated by the functional triad method. The role of phenotypic and genotypic adaptation and the dynamics of their correlation during the algal adaptation to the toxic media has been revealed.

Ghost, T.K., Saha, K.C. (1988) Influence of carbofuran on the growth and nitrogen accretion of blue-green algae (cyanobacteria) *Aulosira fertilissima*. *Indian Agric.* 32(3): 153–161.

*Summary:* The influence of carbofuran on blue-green algae, *Aulosira fertilissima* was studied in relation to growth  $N_2$ -fixation and its forms of accumulation in culture medium and also in two soils (alluvial and lateritic) under waterlogged conditions. In culture medium, carbofuran at the concentration of 10 and 25 ppm significantly increased the chlorophyll content and biomass (dry weight) of the organism with a simultaneous increase in the biomass-nitrogen (intracellular) and extracellular nitrogen content in the culture medium. However, higher doses of carbofuran were found to be toxic in this respect. In soil cultures the tolerance limit of this algae to the concentration of carbofuran was found to be much higher. Nitrogen fixation was encouraged at all levels of insecticide application up to 200 ppm during one and half month of incubation period, although the magnitude of response varied in the two soils. Such algal  $N_2$ -fixation equally benefited the soil with the accumulation of hydrolyzable and available ( $NH_4^+$   $NO_3^-$ ) forms of N. The net mineralization of N due to the growth of blue-green algae had also shown an increase in presence of carbofuran.

Gibson, C.E. (1972) The algicidal effect of copper on a green and a blue-green alga and some ecological implications. *J. Appl. Ecol.* 9: 513-518.

*Summary:* The effect of copper sulphate as an algicide is reviewed briefly. Experiments are described in which *Anabaena flos-aquae* and *Scenedesmus quadricauda* were exposed to different concentrations of copper sulphate. It was found that *A. flos-aquae* was more sensitive to copper than *Scenedesmus quadricauda*. The lethal concentration of accumulated copper was similar for both species. The sensitivity of *Anabaena flos-aquae* to copper varied with the stage of growth of the alga, becoming less sensitive as the culture aged. The implications of these results for the use of copper-based algicides are discussed.

Gingrich, J.C., Buzby, J.S., Stirewalt, V.L., Bryant, D.A. (1988) Genetic analysis of two new mutations resulting in herbicide resistance in the cyanobacterium *Synechococcus* sp. PCC 7002. *Photosynth. Res.* 16(1/2): 83-100.

*Summary:* Two herbicide-resistant strains of the cyanobacterium *Synechococcus* sp. PCC 7002 are compared to the wild-type with respect to the DNA changes which result in herbicide resistance. The mutations have previously been mapped to a region of the cyanobacterial genome which encodes one of three copies of *psbA*, the gene which encodes the 32 kDa Q-binding protein also known as D1 (Buzby et al. 1987). The DNA sequence of the wild-type gene was first determined and used as a comparison to that of the mutant alleles. A point mutation at codon 211 in the *psbA1* coding locus (TTC to TCC) results in an amino acid change from phenylalanine to serine in the D1 protein. This mutation confers resistance to atrazine and diuron at seven times and at two times the minimal

inhibitory concentration (MIC) for the wild-type, respectively. A mutation at codon 211 resulting in herbicide resistance has not previously been described in the literature. A second point mutation at codon 219 in the *psbA1* coding locus (GTA to ATA) results in an amino acid change from valine to isoleucine in the D1 protein. This mutation confers resistance to diuron and atrazine at ten times and at two times the MIC for the wild-type, respectively. An identical codon change conferring similar herbicide resistance patterns have previously been described in *Chlamydomonas reinhardtii*. The atrazine-resistance phenotype in *Synechococcus* sp. PCC 7002 was shown to be dominant by plasmid segregation analysis.

Gleason, F.K., Case, D.E., Sipprell, K.D., Magnuson, T.S. (1986) Effect of the natural algicide, cyanobacterin, on a herbicide-resistant mutant of *Anacystis nidulans* R2. *Plant Sci.* (Shannon) 46(1): 5–10.

*Summary:* Cyanobacterin, a secondary metabolite produced by the cyanobacterium, *Scytonema hofmanni*, inhibits the growth of algae and plants. This compound is a potent inhibitor of photosynthetic electron transport and acts at a site in photosystem II (PS II). To further define the site of action of cyanobacterin, the effects of this natural product were investigated in a herbicide-resistant mutant of the cyanobacterium, *Anacystis nidulans* R2D2-XI. *A. nidulans* R2D2-XI was reported to grow and maintain photosynthetic electron transport in the presence of 20  $\mu$ M 3-(3,4-dichlorophenyl)-1, 1-dimethylurea (DCMU) and 6.0  $\mu$ M atrazine. Resistance was attributed to an altered 32 kDa (quinone-binding, QB) protein [6]. In the presence of Hill electron acceptors, K<sub>3</sub>Fe(CN)<sub>6</sub> and dichlorophenol-indophenol (DCPIP), spheroplasts of *A. nidulans* R2D2-XI were exhibited by cyanobacterin at the same concentration as wild type spheroplasts. Under these same conditions, spheroplasts of the mutant maintained their resistance to DCMU. Similar results were obtained with isolated thylakoid membranes. In contrast, silicomolybdate reduction, which is resistant to DCMU inhibition, was very sensitive to cyanobacterin. We conclude that cyanobacterin inhibits electron transport in PS II at a unique site which is different from that of DCMU.

Golden, S.S., Haselkom, R.H. (1985) Mutation to herbicide resistance Map within the *psbA* gene of *Anacystis nidulans* R2. *Science* 229: 1104–1107.

*Summary:* A *pdsA* gene encoding the target of photosystem II herbicide inhibition, the 30,000-dalton thylakoid membrane protein, has been cloned for a mutant of *Anacystis nidulans* R2, which is resistant to 3-(3,4-dichlorophenyl)-1, 1-dimethylurea- (Diuron). A cloned DNA fragment from within the coding region of this gene transforms wild-type cells to herbicide resistance, providing that mutation within *psbA* is responsible for that phenotype. The mutation consist

of a single nucleotide change that replaces serine at position 264 of the wild-type protein with alanine in that of the diuron-resistant mutant.

Goldsborough, L.G., Robinson, G.G.C. (1986) Changes in periphytic algal community structure as a consequence of short herbicide exposures. *Hydrobiologia* 139(2): 177–192.

*Summary:* Effects of the triazine herbicides simazine and terbutryn on total biovolume and community structure of haptobenthic periphytic algal communities within *in situ* marsh enclosures are described. Levels of biovolume inhibition in excess of 98 percent relative to an untreated control were observed at all levels of terbutryn tested (0.01, 0.1 and 1.0 mg/li). No reduction in total biovolume was observed at 0.1 mg/li simazine, with increasing inhibition (to 98 percent) at 1.0 and 5.0 mg/li. Following incidental enclosure flooding and removal of herbicide, increases in biovolume were observed in all but the highest treatment levels, with rates of colonization similar to that of the control. Pre-flood community structure of periphyton in simazine-treated enclosures was qualitatively similar to that of the control, while a small blue-green alga was abundant only in terbutryn-treated enclosures. After flooding, substratum colonization in most experimental enclosures was dominated by the diatom *Cocconeis placentula*, while this taxon accounted for about 25 percent of total biovolume on substrata from the control and 0.1 mg/li simazine enclosures. It is concluded that periphyton successional processes, which normally lead to the development of a complex 3-dimensional mat, may be averted by short herbicide exposures.

Goulding, K.H., Wynne Ellis, S. (1981) The interaction of DDT with two species of freshwater algae. *Environ. Pollut. Ser. A Ecol. Biol.* 25(4): 271–290.

*Summary:* Whereas the growth of the blue-green alga *Anabaena variabilis* was unaffected by 1 g/ml DDT, the growth of *Chlorella fusca* was affected by 0.1 g/ml. The amount of inhibition varied with time and with the method of growth measurement. When growth was assessed by cell numbers it was maximally inhibited (75 percent) after 72 h by 1.0 g/ml DDT. After 200 h cell numbers were the same as the control. Subsequently they exceeded the control cultures. When growth was determined by chlorophyll a or total culture biovolume the new inhibition was more marked and growth only equalled that of the control at the end of the experiment (480 h). This apparent anomaly was explained by the observation that treated cells were considerably smaller and more ovoid than control cells. The initial inhibition of growth of *C. fusca* by 1.0 g/ml DDT was greater at lower initial cell inoculum sizes, but was not affected by pH aeration conditions or phosphate concentration of the growth medium. Both algae accumulated <sup>14</sup>C-DDT. The amount accumulated was much higher in *C. fusca* than



in *A. variabilis*. Neither alga significantly metabolized DDT although cells of *C. fusca* contained a small amount of DDE after 480 h incubation with the insecticide.

Goyal, S.K. (1986) Interaction between pesticides and cyanobacteria. Pages 93–96 in Radhir Singh Naihawahe, H.S., Sawhney, S.K. (ed.), *Current status of biological nitrogen fixation research*, H.A.U. Hissar, India. (NC)

Grant, I.F., Eagan, F.A., Alexander, M. (1983) Pesticides to control Ostracod grazing on blue-green algae (*Cyanobacteria*). *Soil Biol. Biochem.* 15: 193–197.

*Summary:* Means to control ostracods grazing on blue-green algae (cyanobacteria) important in fixing nitrogen in flooded rice soils were studied. The relative acute lethal toxicity (LC48/50) to the ostracods *Cyprinotus carolinensis* and *Heterocypris luzonensis* grazing on *Tolypothrix tenuis* was 0.4 and 2.4 g/ml for carbofuran and 4.5 and more than 56.0 g/ml for lindane. Complete inhibition of grazing was achieved with 1.0 and 25 g carbofuran/ml and 0.1 and 5.6 g lindane/ml for *C. carolinensis* and *H. luzonensis*, respectively. Lindane at concentrations below 0.02 g/ml stimulated feeding by *C. carolinensis* on the alga. Breakdown of carbofuran markedly reduced its effectiveness as a measure to control grazing, but lindane did not rapidly lose its effectiveness. The toxicity of carbofuran to *C. carolinensis* feeding on *T. tenuis* was not affected by pH. The difference in ostracod responses to the pesticides, which may be associated with resistance acquired through previous exposure, is an important consideration in designing practical means to reduce grazing in paddy fields.

Grant, I.F., Roger, P.A., Watanabe, I. (1986) Ecosystem manipulation for increasing biological N<sub>2</sub> fixation by blue-green algae (*Cyanobacteria*) in lowland ricefields. *Biol. Agric. Hort.* 3: 299–315. AB Academic Pub. U.K.

*Summary:* An introduction to the soil/floodwater ecosystem of lowland ricefields is given. Two primary consumers are particularly important in limiting the growth and N<sub>2</sub>-fixing activities of blue-green algae in irrigated rice; the Ostracoda (Class Crustacea) and the Pulmonata (Mollusca). Control of grazing by neem seeds *Azadirachta indica* A. Juss and cultural practices enhanced BGA biomass and increased N<sub>2</sub>-fixation ten fold. Significant increases in rice grain protein occur if heterocystous algae bloom early in the rice cultivation cycle and grazing control is maintained over 40 days. A large positive N balance was obtained over three rice crops by using neem seeds to control grazing of BGA. Algal inoculants used in conjunction with grazer control failed to establish themselves, and factors other than grazing were considered responsible. Plant-derived pesticides showed great promise for sustainable agriculture.

Grant, I.F., Seegers, R., Watanabe, I. (1984) Increasing biological nitrogen fixation in flooded rice using neem. Pages 493–505 in Schmutterer, H. and Ascher, K.R.S. (eds.), *Natural pesticides from the neem tree and other tropical plants* G.T.Z. Eschborn, F.R.G.

**Summary:** The antifeedant properties of neem extracts to *Heterocypris luzonensis* Neale (Ostracoda) were investigated. These aquatic crustaceans are particularly successful in colonizing wetland ricefields, where they can limit the establishment, growth and N<sub>2</sub>-fixing activities of blue-green algae. Passive aqueous extracts of neem seeds and Soxhlet extractions of neem seed or cake in acetone or water did not affect grazing of *H. luzonensis* on *Tolypothrix tenuis* (Cyanophyta) within 2 h of exposure. However, passive aqueous extracts of neem seed substantially reduced grazing after 4 days of exposure. A 1.6 ppm aqueous solution of a crude extract of azadirachtin (15–18 percent in acetone) inhibited feeding completely and instantaneously. Greenhouse pot experiments were designed to study the effect of alleviating ostracod grazing pressure on N<sub>2</sub> fixing blue-green algae by applying neem seed and neem cake to the floodwater. Total nitrogen (N) inputs and outputs of the plants/soil/water system were measured over five rice harvests and the positive N balances obtained were attributed to biological N<sub>2</sub> fixation. A highly significant and large positive N balance was obtained in soils treated with neem seed. Neem cake applications did not increase N balance significantly when compared with an untreated control. When algal growth was prevented by covering soils with a black cloth, only a small N balance was maintained. Nitrogen uptake by grain and straw from pots treated with or without neem seed or cake was similar, but that from soils covered by a black cloth was 30 percent less. Neem had no direct effect upon growth of the rice plant. Effects of neem application on N balance were considered with reference to N-fixation, antifeedant properties, and inhibition of nitrification.

Grant, I.F., Tirol, A.C., Aziz, T., Watanabe, I. (1983) Regulation of invertebrate grazers as a means to enhance biomass and nitrogen fixation of *Cyanophyceae* in wetland ricefields. *Soil Sci. Soc. Amer. J.* 47: 669–675.

**Summary:** The effect of invertebrate grazing on the growth and N<sub>2</sub> fixation of blue-green algae (Cyanophyceae) in flooded rice soils was investigated by depressing grazer populations. Grazers were controlled with commercial pesticides and seeds of neem (*Azadirachta indica*). Algal N<sub>2</sub> fixation and standing biomass were estimated by acetylene-reduction activity and chlorophyll a measurements. Suppression of ostracod (Ostracoda) grazing by Perthane or neem seeds tripled blue-green algal biomass and increased N<sub>2</sub> fixation rates 10-fold. In the absence of ostracods, free living blue-green algae multiplied rapidly early in the rice cultivation cycle to be succeeded by chlorophytes. Carbofuran was not an effective

control measure. Suppression of molluscan grazing had little effect. The population of tubificids (Tubificidae) was higher in the plots where algal growth was stimulated than in other plots. Total rice grain N was increased up to 37 percent when grazing was arrested.

Gregory, W.W., Reed, J.K., Priester, L.E. (1969) Accumulation of parathion and DDT by some algae and protozoa. *J. Protozool.* 16: 69. (NC)

Gupta, G.S., Saxena, P.N. (1974) Effect of panacide on some green and blue-green algae. *Curr. Sci.* 43(15): 492–493. (NS)

*Notes:* *In vitro* tests with 30 concentrations ranging from 1 to 80 ppm of panacide (Dichlorophen) on *Scenedesmus obliquus*, *Chlorella pirenoidosa*, *Myxosarcina spectabilis*, *Aulosira prolifica*, and *Nostoc* sp. Marked inhibitions were recorded at concentrations higher than 20 ppm for the eukaryotic algae and higher than 10 ppm for the *Nostoc* sp.

Gupta, S.L. (1983) Acid phosphatase and alkaline phosphatase activity in the cyanobacterium *Anacystis nidulans* under copper stress. *Folia Microbiol.* 28(6): 458–462.

*Summary:* The effect of lethal concentration of Cu ions on the activities of acid and alkaline phosphatases was investigated in the cyanobacterium *A. nidulans* and the cyanophage AS-1 resistant mutant. When the level of phosphatase (periplasmic protein) and acid phosphatase (cytoplasmic protein). In the presence of Cu, the level of enzymes was low, suggesting that synthesis and activity were not completely abolished by Cu. This may be related to the permeability of cell membrane.

Gupta, S.L. (1985) Influence of inorganic nitrogen nutrients on copper toxicity in *Anacystis nidulans* and cyanophage AS-1 resistant mutant. *Bull. Bot. Surv. India* 27(1–4): 142–144.

*Summary:* The effect of different nitrogen sources on growth and copper toxicity was studied in the unicellular cyanobacterium *Anacystis nidulans* and Cyanophage AS-1 resistant mutant (An/AS-1). The mutant An/AS-1 was characterized by slow growth rate but was more sensitive to copper than its parent. In both the strains, the presence of high nitrate concentrations, which supported better growth of algae, reduced the algicidal effect of copper. However, other inorganic nitrogen sources such as nitrite and ammonium caused more inhibition and reduced the specific growth rate. Mean autotrophic productivity, estimated by  $^{14}\text{C}$ -bicarbonate uptake in daylight, ranged from 0.30–2.8 mg C/m<sup>2</sup>/ha.

Autotrophic productivity was reduced by 57–81 percent at 2.5 g/li CuT, 55–96 percent at 5 g/li CuT, and 81–100 percent at 10 g/li CuT. Heterotrophic productivity (based on dark  $^{35}\text{S}$ -sulfate uptake) was inhibited to a lesser extent (28–63 percent at 2.5 g/li CuT, 24–84 percent at 5 g/li CuT and 67–92 percent at 10 g/li CuT). The inhibition of autotrophic and heterotrophic productivity persisted through the year of exposure. Production in stream sections previously exposed to 2.5 and 5 g/li CuT increased to control levels within four weeks after dosing, but remained depressed for more than seven weeks after exposure to 10 g/li CuT. The specific rate of photosynthesis (mg C mg chlorophyll/a/h) of mature periphyton communities declined at all test concentrations of Cu, but the rate for periphyton on newly-colonized surfaces did not change. The species composition of benthic algae shifted during exposure to an assemblage more tolerant of Cu. *Achnanthes minutissima* and *Fragilaria crotonensis* were the primary replacement species on newly-colonized surfaces. The nitrogenase activity of blue-green algae was low, with controls ranging from 2.4–12 nmol  $\text{C}_2\text{H}_2/\text{m}^2/\text{h}$ . Nitrogenase activity was inhibited during the initial weeks of exposure by 5 and 10 g/li CuT. After nine months of exposure, control and Cu-treated sections did not differ. The rate of processing of leaf litter, estimated by microbial respiration and nutrient quality of litter of resident riparian woodland taxa, was inhibited at all test concentrations of Cu.

Hamdi, Y.A., ElNawawy, A.S., Tewfik, M.S. (1970) Effect of herbicides on growth and nitrogen fixation by alga *Tolypothrix tenuis*. *Acta Microbiol. Pol. B* 2(19): 53–56. (NS)

*Notes:* Hamdi et al. (1970) treated cultures of *T. tenuis* with 0.1, 1, and 10 times the recommended dose of Ordram, trifluralin, 2,4D, or Stam either at the time of culture inoculation or 10 days after inoculation. At both times and all concentrations there was a reduction in dry weight and N content measured after 35 days of growth, and a stimulation in chlorophyll content. Ordram; 0.25 ppm, 30 percent inhibition; 2.5 ppm, 30 percent inhibition; 25 ppm 80 percent inhibition, Trifluralin: 0.25 ppm, 25 percent inhibition; 2.5 ppm, 45 percent inhibition; 25 ppm 80 percent inhibition. 2,4D: 0.045 ppm, 25 percent inhibition; 0.45 ppm, 45 percent inhibition; 4.5 ppm 30 percent inhibition. Stam: 0.18 ppm, 25 percent inhibition; 1.8 ppm, 45 percent inhibition; 18 ppm total inhibition.

Hartz, P.H. Rochling, Mariouw-Smith, F. (1972) 2-dichloro-aceta-mido-3-chloro-1,4-naphthoquinone, a new algicide for application in rice and other cultures. *Meded. Fac. Landbouw-wetensch Rijksuniv Gent* 37: 699. (NC)

Hatfield, P.M., Guikema, J.A., St. John, J.B., Gendel, S.M. (1989) Characterization of the adaptation response of *Anacystis nidulans* to growth in the presence of sublethal doses of herbicide. *Curr. Microbiol.* 18(6): 369–374.

*Summary:* Cells of the cyanobacterium, *Anacystis nidulans*, were cultured in the presence of sublethal doses of the herbicides DCMU [3-(3,4-dichlorophenyl)-1, 1-dimethylurea] and terbutryn (a triazine). The responses observed were characteristic of photosynthetic organisms grown under low light conditions. The contents of the accessory pigment phycocyanin increased in relation to chlorophyll. Moreover, each dose of herbicide was correlated with defined changes in the pigment profile. Data obtained from chlorophyll fluorescence measurements indicated that the additional phycocyanin was functionally integrated into phycobilisomes, probably into newly formed phycobilisomes. The concentration of fatty acids in the total polar lipid fraction (per milligram chlorophyll) was greater in adapted than in control cells; nevertheless, the ratio of unsaturated fatty acids remained unchanged. Measurable rates of photosynthetic electron transport were similar among herbicide-adapted cultures and controls. These data are consistent with the hypothesis that herbicide treatment impaired electron transport, but that function was restored by the adaptation response. Furthermore, this response is conserved among cyanobacteria and higher plants, indicating that this flexibility is extremely significant to photosynthetic function.

Hawxby, K., Tubea, B., Ownby, J., Basler, E. (1977) Effects of various classes of herbicides on four species of algae. *Pest. Biochem. Physiol.* 7: 203–209.

*Summary:* *Chlorella pyrenoidosa*, *Chlorococcum* sp., *Lyngbya* sp., and *Anabaena variabilis* were cultured in Bold's basal medium. They were treated with 0.1, 1.0, and 10 M concentrations of 2-chloro-2', 6-diethyl-N-(methoxymethyl) acetanilide (alachlor), 2-chloro-4-(ethylamino)-6-(tert-butylamino)-s-triazine (terbuthylazine), 2-sec-butyl-4,6-dinitrophenol (dinoseb), 1, 1-dimethyl-3-(trifluoro-2,6-dinitro-N-propyl-p-toluidine) (profluralin), 2 4-bis(isopropylamino)-6-(methylthio)-s-triazine (prometryne), and (2,4-dichlorophenoxy) acetic acid (2,4-D). Growth of all algal species tested was markedly reduced by the triazines. Alachlor, dinoseb, and fluometuron inhibited growth of some algae at higher concentrations while 2,4-D and profluralin did not inhibit growth at the concentrations tested. Photosynthesis was greatly inhibited by the triazines, even at the 0.1 M concentration. Fluometuron was very toxic to the blue-green algae but had less effect on the green algae tested. *Lyngbya* was most susceptible to photosynthesis reduction by the herbicides. The concentrations of herbicides tested had little effect on respiration of the algae species. It appears that effect on algal growth were due primarily to inhibition of photosynthesis rather than to other metabolic processes.

Holst, R.W., Yopp, J.H., Kapusta, G. (1982) Effect of several pesticides on the growth and nitrogen assimilation of the *Azolla-Anabaena* symbiosis. *Weed Sci.* 30: 54–58.

*Summary:* Of 15 pesticides evaluated in a screening test with respect to their effects on growth and nitrogen assimilation of the *Azolla mexicana* (Presl)—*Anabaena azollae* (Strasburger) symbiosis, the bipyridilium and phenolic herbicides at 0.1 ppm were the most detrimental, causing up to a 75 percent reduction in nitrogen fixation and nitrate reduction with little or no effect on growth. Chloramber [3-amino-2,5-dichlorobenzoic acid], and benomyl [methyl-1-(butyl-carbamoyl)-2-benzimidazolyl carbamate] at 10.0 ppm caused an 84 to 99 percent reduction in nitrogen fixation without affecting nitrate reduction or growth. Simazine [2-chloro-4,6-bis(ethylamino)-s-triazine] at 10.0 ppm stimulated nitrate reduction 20 fold, causing a 99 percent reduction in nitrogen fixation. Growth and nitrogen assimilation were reduced at similar concentrations between 0.1 and 10 ppm for each of the other benzoic, triazine, dinitroaniline, and urea herbicides tested. Naptalam [N-1-naphthylphthalamic acid] was the only pesticide tested that had no effect on growth or nitrogen assimilation at 10.0 ppm.

Hutber, G.N., Rogers, L.J., Smith, A.J. (1979) Influence of pesticides on the growth of cyanobacteria. *Zeit. Allg. Mikrobiol.* 19(6): 397–402.

*Summary:* Two unicellular and two filamentous cyanobacteria were exposed under conditions optimal for photoautotrophic growth to 11 pesticides. Low concentrations (0.01 to 5 ppm) of diuron, atrazine, and paraquat inhibited growth. With MCPA, MCPP, 2,4-D, Milstem and Ethrel, marked inhibitory effects were achieved only at concentrations above 100 ppm. Growth was inhibited by DDT, glyphosate, and Thiram at intermediate concentrations. In some cases, the effective concentration of the pesticide varied considerably with the organism tested.

Ibrahim, A.N. (1972) Effect of certain herbicides on growth of nitrogen-fixing algae and rice plants. *Symp. Biol. Hung.* 11: 445–448. (NS)

*Notes:* *In vitro* test of four herbicides (Eptam 6-E, Stam F-34, Ordram, and Trifluralin) on blue-green algae *Tolypothrix tenuis* and *Calothrix brevissima*.

Inger, L. (1970) Effect of two herbicides on nitrogen fixation by blue-green algae. *Sven. Bot. Tidskr.* 64: 460–461.

*Summary:* 2,4-D and MCPA affect the nitrogen fixation by *Nostoc muscorum*, *N. punctiforme* and *Cylindrospermum* at concentrations recommended for field application but stimulated nitrogen fixation at  $10^{-4}$  to  $10^{-5}$  M concentrations.

Ionescu, A.L. (1985) Restructuring of algocenoses in the soil under the influence of herbicides. *Stud. Cercet. Biol. Ser. Biol. Veg.* 37(1): 47–52.

*Summary:* The utilization of herbicides in various crops influences the quantitative and numeric composition of the edaphic flora. Analyzing in time the phytocenosis structure (algocenosis, mainly) it was established that its remarking may indicate, with precision, the absence of active remnent ingredients of the herbicide used. The paper surveyed the experiments regarding the determination of total number of microorganisms, on a medium containing soil extract, the identification of the species, and the number of algae and also regarding the ability of mineralizing the humus and of nitrifying the N resulted.

Ishizawa, S., Matsuguchi, T. (1966) Effects of pesticides and herbicides upon microorganisms in soil and water under waterlogged condition. *Bull. Nat. Inst. Agric. Sci B* 16: 1–90.

*Notes:* Experiment in 200 ml beakers with 70 g soil and 170 ml distilled water. When lime and Pentachlorophenol (PCP) were mixed with the soil, BGA growth was stimulated by liming, not affected by 120 ppm PCP incorporated, and was retarded by 600 and 1200 ppm. Surface application of PCP with or without urea was depressive to BGA and diatoms with long residual effect. Low levels of gamma BHC inhibited diatoms but not BGA. NAC and Ruberon had no effect on algae. Chloropicrin affected all kinds of algae.

Ito, K., Chiba, Y. (1978) Studies on preventive methods for film-like separating of surface soil at the paddy field with mixed use of herbicides. *Tohoku Agric. Res.* 23: 39–40.

*Notes:* (In Japanese with no English summary)

Kar, S., Singh, P.K. (1978) Toxicity of carbofuran to blue-green alga *Nostoc muscorum*. *Bull. Environm. Contam. Toxicol.* 20: 707–714.

*Summary:* Effect of commercial grade furadan (3 percent ai as carbofuran) was studied on the survival, growth and N<sub>2</sub> fixation of blue-green alga *Nostoc muscorum*. The lower concentration of furadan i.e. 25 g/ml enhanced survival, growth and N<sub>2</sub> fixation in the alga whereas these were gradually inhibited in higher concentrations (50–1,000 g/ml) and the presence of more than 1,200 g/ml was algicidal. The preliminary observations revealed that pesticide is biodegraded by the alga.

Kar, S., Singh, P.K. (1979a) Detoxication of pesticide carbofuran and hexachlorocyclo-hexane by blue-green algae *Nostoc muscorum* and *Wollea bharadwajae*. *Microbios Lett.* 10: 111–114.

*Summary:* The N<sub>2</sub> fixing blue-green algae *Nostoc muscorum* and *Wollea bharudwajae* were employed in detoxification tests of the pesticides carbofuran and hexachlorocyclohexane containing growth media. It was observed that the toxic effect of these chemicals was reduced by repeated inoculation and removal of blue-green algae, which indicated that pesticides are accumulated or detoxified in the algal cells.

Kar, S., Singh, P.K. (1979b) Effect of nutrients on the toxicity of pesticides carbofuran and hexachlorocyclohexane to blue-green alga *Nostoc muscorum*. *Zeits. Allg. Mikrobiol.* 19(7): 467-412.

*Summary:* The effects of various levels of nutrients like potassium phosphate (dibasic), calcium nitrate, and calcium chloride, individually and in combinations, were studied on the toxicity of the commonly used pesticides carbofuran and hexachlorocyclohexane (HCH) in growth medium to the N<sub>2</sub>-fixing blue-green alga *Nostoc muscorum*. It was observed that all these chemicals had some effects on toxicity. The toxicity of both carbofuran and HCH was reduced to some extent in the presence of higher concentrations of the nutrients when compared to normal levels of the chemicals in the medium. The higher doses of nutrients in combinations antagonized the effect of individual treatment and enhanced the toxicity of pesticides.

Kar, S., Singh, P.K. (1979c) Effect of pH, light intensity and the population on the toxicity of the pesticide carbofuran to the blue-green algae *Nostoc muscorum*. *Microbios Lett.* 21: 177-184.

*Summary:* The effect of pH, light intensity and population on the toxicity of the pesticide furadan (containing 3 percent carbofuran as the active ingredient) was studied on the N<sub>2</sub> fixing blue-green alga *Nostoc muscorum*. It was observed that all these factors had effects on the toxicity of the pesticide. The blue-green alga grew better in the pH range of 7.5-10, whereas the acidic pH of 5-6 retarded growth. The pesticide was more toxic to alga in the medium of pH 5-6, whereas reduction in toxicity was noticed in alkaline pH of 7.5-10. The alga grew slowly in a light intensity of 1,500 lux in comparison to a light intensity of 3,000 lux, and no growth occurred in the dark. The toxicity of the pesticide gradually decreased with increasing light intensity. The toxic effect of the pesticide was increased when the initial population level was low, and increasing the initial population reduced the toxicity.

Kashyap, A.K., Gupta, S.L. (1981) Effects of dichlone on growth, macromolecular synthesis and photosynthetic pigments in blue-green algae. *Acta Bot. Indica* 9: 265-271.



*Summary:* Effects of dichlone on blue-green algae *Anacystis nidulans* (unicellular, non-N<sub>2</sub> fixing), *Nostoc calcicola*, *N. muscorum* and *Anabaena cylindrica* (filamentous and nitrogen fixing) was investigated. Low concentrations of dichlone stimulated growth of all the blue-green algae, while decrease in specific growth was observed at higher concentrations. Data based on specific growth rates suggested that *A. cylindrica* was more resistant and *A. nidulans* was most sensitive while other species possessed sensitivity of intermediate level. Dichlone was found to affect pigment composition in all the algal strains where phycocyanin was the first component to be affected. Since addition of nitrate to the medium partially reversed the lethal effects of dichlone, it was suggested that N<sub>2</sub> fixation (in N<sub>2</sub> fixing species) was primarily affected by dichlone. Depletion of phycocyanin supported this notion. Nevertheless, inhibition of nitrogen could as well result from the blockage of primary processes of photosynthesis.

Kashyap, A.K., Pandey, K.D. (1982) Inhibitory effects of rice-field herbicide Machete on *Anabaena doliolum* and protection by nitrogen sources. *Z. Pflanzenphysiol.* 107(4): 339-346.

*Summary:* Machete [2-chloro-2',6'-diethyl-N(butoxymethyl) acetanilide], a ricefield herbicide, is toxic to the N<sub>2</sub> fixing blue-green alga *Anabaena doliolum*. While low concentrations (0.05 g/ml) had stimulatory effects, algal growth was completely inhibited at 20 g/ml machete. Sublethal concentration (5.0 g/ml) of the herbicide resulted in the decline of protein and phycobilin levels with no apparent effect on chlorophyll a, carotenoids carbohydrate, DNA and RNA. The herbicide inhibited heterocyst differentiation and nitrogen fixation. In contrast to vegetative cells, spores were more resistant to the herbicide. Since toxicity of the herbicide could be reversed by inorganic nitrogen sources (nitrate, nitrite and ammonium), it is suggested that N<sub>2</sub> fixation was sensitive to the herbicide.

Kaushik, B.D., Venkataraman, G.S. (1983) Response of cyanobacterial nitrogen fixation to insecticides. *Current Science* 52(7): 321-323 (NS).

*Notes:* *In vitro* study of the effect of gamma BHC, carbofuran, and Phorate on five BGA. Concentrations tested ranged from 1 to 100 ppm. Total chlorophyll content and acetylene reducing activity of the cultures were tested, showing stimulatory effects or no effects at concentrations corresponding to the field level of application.

Kayumov, V. (1963) Use of copper sulfate for control of algae on ricefields. *Kolkhoz. Sovkhoz. Proizv. Turkmenistana* 6: 37-38 (In Russian). (NC)

Kayumov, V. (1965) Use of copper sulphate in control of algae on ricefields. *Kolkhoz Sovkhoz Proizv. Tadzhikistana* 6: 54 (In Russian). (NC).

Khalil, Z., Mostafa, I.Y. (1986) Interactions of pesticides with fresh-water algae: 1. Effect of methomyl and its possible degradation by *Phormidium fragile*. *J. Environ. Sci. Health Part B Pestic. Food. Contam. Agric. Wastes* 21(4): 289–302.

*Summary:* The insecticide methomyl showed no significant effect on the growth of the freshwater alga *Phormidium fragile* up to a concentration of 112.5 ppm. However, at higher concentrations inhibition was observed. Biochemical analysis showed a gradual decrease in all nitrogen fractions, total carbohydrate content, chlorophyll a and carotenes contents. Furthermore, a considerable decrease in the amount of both soluble and insoluble phosphorus fractions was also observed. The organism was capable of degrading 48.6 percent of the applied radiolabelled insecticide of which only 0.1 percent of  $^{14}\text{C}$ -activity was trapped as  $^{14}\text{CO}_2$ . Furthermore, the chloroform and aqueous fractions contained 50.4 percent and 35.0 percent, respectively of the initial radioactivity. Thin-layer chromatographic analysis showed the presence of three metabolites of methomyl one of which was identified as the oxime.

Khasanova, L.A., Vagner, I. (1988) Effect of sublethal copper ion concentrations on the cells of the cyanobacterium *Synechocystis aquatilis*. *Vestn. Leningr. Univ. Biol.* 0(1): 83–88.

*Summary:* The effect of sublethal concentration of copper ions on cyanobacterium *Synechocystis aquatilis* was studied. A decrease in salt tolerance was observed, suggesting disturbances in cytoplasmic membrane. In response to copper ions the growth rate and photosynthetic activity of *Synechocystis aquatilis* decreased.

Kerni, P.N., Shant, P.S., Gupta, B.B., Singh, D. (1984) Effect of granular butachlor on the functioning of blue green algae in paddy fields. *Pesticides* 18(10): 21–22.

*Summary:* Insignificant differences in crop yield of paddy, variety Ratna during 1976 to 1978 in Kharif seasons, revealed that weed eradication with 30 kg/ha of butachlor (G) did not effect normal functioning of blue green algae, when both were used simultaneously in paddy fields. However, 15 kg/ha of butachlor (G) which recorded the highest yield every year, elucidated a compromising dose for better functioning of blue-green algae when compared to various doses of the weedicide.

Kerni, P.N., Shant, P.S., Singh, D., Gupta, B.B. (1983) Effect of butachlor (G) on blue green algae in rice farms. *Science and Culture* (May): 138. (NS)

*Notes:* Field experiment on simultaneous utilization of BGA inoculation and herbicide. Both methodology and conclusions are questionable.

Khalil, K., Chaporkar, C.B., Gangawane, L.V. (1980) Tolerance of blue-green algae to herbicides. Pages 36–39 in *Proceedings of the National Workings of Algal Systems*. Indian Soc. Biotechnology, IIT/New Delhi 110016, India.

*Summary:* Tolerance of 2,4-D by *Mastigocladus laminosus* was more than 1000 ppm. Only 100 ppm of Tolkan and Basalin was tolerable to this alga. Growth was reduced considerably as the concentration of herbicides increased. However, 500 ppm of 2,4-D was found to be stimulatory. Nitrogen content in both the dry matter and culture filtrate were reduced two and ten folds respectively due to herbicides at the tolerance level. Heterocyst counts increased at 1 to 50 ppm due to 2,4-D while in other cases there was many fold reduction. *Tolypothrix tenuis* showed its tolerance at 500, 100 and 50 ppm to 2,4-D, Tolkan and Basalin respectively. Growth, nitrogen fixation and heterocyst formation were affected considerably, this being more prominent in Tolkan and Basalin respectively showing various growth levels. Growth was more affected due to Basalin while nitrogen fixation due to 2,4-D.

Kikuchi, R., Yasutaniya, T., Takimoto, Y., Yamada, H., Miyamoto, J. (1984) Accumulation and metabolism of fenitrothion in three species of algae. *J. Pestic. Sci.* (Nihon Noyaku Gakkaishi) 9(2): 331–338.

*Summary:* *Chlorella vulgaris*, *Nitzschia closterium* and *Anabaena flos-aquae* rapidly absorbed fenitrothion, O,O-dimethyl O-(3-methyl-4-nitrophenyl) phosphorothioate, from medium, and the maximum bioaccumulation ratio in terms of dry weight was 44, 105 and 53, respectively. On transference of these algae to fenitrothion-free medium, the concentrations of  $^{14}\text{C}$  and fenitrothion decreased rapidly, with half-lives of 1–15 hr and 1–2.6 hr, respectively. *A. flos-aquae* metabolized fenitrothion most actively to its oxon and demethyl analogs and its phenol, whereas *C. vulgaris* decomposed the chemical not to the oxon analogs, but to demethylfenitrothion. In contrast, DDT showed higher accumulation ratios of 433–82,000 and longer half-lives of 17–201 hr under similar conditions.

Kobbia, L.A. (1982) Response of phytoplankton populations in some Egyptian irrigation drains to the aquatic weed herbicide “acrolein.” *Egypt J. Bot.* 25(1-3): 41–68.

**Summary:** The effects of the herbicide “acrolein” of the phytoplankton populations in Egyptian drains were studied. The results show some statistically significant differences in standing crop biomass and Species Diversity Index (SDI) between treated and untreated sites. Cyanophycean members appeared to be the most tolerant phytoplankton organisms to acrolein followed by Bacillariophycean cells. They rapidly recover and restore their vitalities.

Kobbia, I.A., Salama, A.M., Shabana, E.F. (1987) Changes in growth, carbohydrate and nitrogen metabolic processes in *Anabaena flos-aquae* and *Phormidium fragile* (Cyanophyta), under the combined effect of amitrole and dalapon. *Cryptogam. Algol.* 8(1): 19–28.

**Summary:** The herbicide mixture of amitrole and dalapon appreciably attenuated the gain in dry weight of *Anabaena flos-aquae* (Lyngb.) Breb. but stimulated the growth of *Phormidium fragile* Gom. Chlorophyll a biosynthesis was arrested in both algae. The total carbohydrates were significantly lowered in *Anabaena*, but remarkably increased in *Phormidium*, a trend that was associated with a similar rise in polysaccharide level. The mixture particularly at higher doses, increased external nitrogen secretion, and nitrate uptake. The total nitrogen content was increased in both organisms. The gain in the total soluble nitrogen fraction, was always much higher than the gain in the total insoluble nitrogen fraction.

Kostlan, N.V. (1980) Effect of copper ion concentration on respiration intensity in Chlorophyta and Cyanophyta. *Ukr. Bot. Zh.* 37(3): 51–53.

**Summary:** Effect of  $\text{Cu}^{2+}$  on the aerobic respiration of blue-green alga *Spirulina platensis* (Gom.) Geitl, and green algae *Chlorella vulgaris* Beijer, strain 18 (autotroph) and *C. pyrenoidosa* Chick, strain G-9 (the pigment mutant) depending on the culture age and nutrition conditions. The green and blue-green algae differ sharply in sensitivity of aerobic respiration to the given inhibitor: in the green algae a considerable inhibition of this process was observed at the concentration of  $\text{Cu}^{2+}$  considerably lower than in the blue-green ones. The  $\text{Cu}^{2+}$  effect on the cytoplasmic membranes may reflect a specificity of the cell membrane systems of the algae differing in taxonomic position and a variability of these systems under the effect of physiological and ecological factors.

Kumar, D., Jha, M., Kumar, H.D. (1985) Copper toxicity in the freshwater cyanobacterium *Nostoc linckia*. *J. Gen. Appl. Microbial.* 31(2): 165–170.

**Summary:** The effect of copper ( $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ ) on growth, heterocyst frequency, acetylene reduction,  $\text{H}_2$  production and photosynthetic  $\text{O}_2$  evolution of *Nostoc*

*linckia* was studied. Whereas copper inhibited growth and other physiological processes, it increased heterocyst frequency and  $H_2$  production. We conclude that copper pollution could considerably alter nitrogen dynamics in freshwater systems.

Kumar, H.D. (1963) Inhibition of growth and pigment production of a blue-green alga by 3-amino-1,2,4-triazole. *Indian J. Plant Physiol.* 6: 150–155.

*Summary:* The growth and pigment production of the unicellular blue-green alga *Anacystis nidulans* are reversibly inhibited by relatively low concentrations of 3-amino-1,2,4-triazole.

*Notes:* 10 ppm had no effect while the next concentration tested (50 ppm) reduced growth measured after 10 days by about 95 percent.

Kumar, H.D., Singh, H.N. (1981) *Biological action of common herbicides on nitrogen fixing potential of paddy fields*. Final report DST Project No. 11 (44) 176 SERC, Centre of Advanced Study in Botany, Banaras Hindu University. pp. 1–21.

*Summary:* From our study lasting over three years it is obvious that the response of different organisms to different herbicides varies. In all the cases there was total cessation of growth of the tested organism at certain concentrations of the herbicide. Although the relative tolerance of the organisms to these agricultural chemicals showed a pronounced difference, the mode of action of the herbicide seemed to be similar as is clear from the study with organic sources. It has been reported that most of the herbicides affect photosynthetic process and in such study at least impairment of PS-II may be overcome by the exogenous supplementation of utilizable carbon source. Lasso and Machete were found to be ineffective in blocking the PS-II system. But Saturn and Simazine seem to affect PS-II and on addition of exogenous utilizable carbon sources the impairment in PS-II was overcome to some extent. Concomitant with the growth inhibition caused by Lasso and Machete there was absence of nitrogenase activity. Hence their adverse side effect on nitrogen process seems warranted.

Kumar, S. (1988) Effects of pesticides on nitrogen-fixing blue-green algae. Vol. 3. Pages 129–155. in *Pesticides and Nitrogen Cycle*, Rup Lal and Sukanya Lal (eds.). Boca Raton: CRC Press

*Notes:* A review with 139 references and summary of toxicity tests performed with 61 pesticides on various BGA.

Kumar, S., Lal, R., Bhatnagar, P. (1988) Uptake of dieldrin, dimethoate and permethrin by cyanobacteria, *Anabaena* sp. and *Aulosira fertilissima*. *Environ. Pollut.* 54(1): 55-62.

*Summary:* Blue-green algae showed a poor ability to pick up and concentrate dieldrin and dimethoate. However, the uptake and bioconcentration factor for permethrin was very high. The uptake of dieldrin by *Anabaena* and *Aulosira* ranged from 5.1 to 73.2 and 5.5 to 174.4 µg/g (ppm), respectively. The uptake of permethrin was from 9.0 to 249.7 and 4.6 to 1,422.5 µg/g by *Anabaena* and *Aulosira*, respectively. The highest bioconcentration factors for permethrin in *Anabaena* and *Aulosira* were 813 and 2,373, respectively. This was followed by the bioconcentration factor of dieldrin (620) and dimethoate (119) in *Aulosira fertilissima*.

Lal, S. (1984) Effects of insecticides on algae. Chapter 9 in *Insecticide microbiology*, Lal, R. (ed.), Springer-Verlag, Basel. (NS)

Lal, S. (1985) Interaction of blue green algae, a ciliate protozoan and yeast with DDT, fenitrothion and chlorpyrifos, Ph.D. thesis, Delhi University, India. (NC)

Lazaroff, N., Moore, R.B. (1966) Selective effects of chlorinated insecticides on algal populations. *J. Physiol.* 2: 56. (NC)

Lederman, T., Rhee, G.-Yull. (1982) Bioconcentration of a hexachlorobiphenyl in Great Lakes: planktonic algae. *Can. J. Fish. Aquat. Sci.* 39(3): 380-387.

*Summary:* The bioconcentration of 2,4,5,2',4',5'-hexachlorobiphenyl (HCB) was examined in the Great Lakes algae *Fragilaria crotonensis*, *Ankistrodesmus falcatus* and *Microcystis* sp. The bioconcentration factors varied with species, whether they were expressed in terms of cell number, dry weight, cellular C, or cellular lipid. The factors were in the range of  $10^5$ - $10^6$  and increased with decreasing biomass. The existence of a mucilage layer in *F. crotonensis* was associated with a two-fold increase in the bioconcentration factor. Surface adsorption apparently contributed only slightly to the bioaccumulation of HCB. HCB desorbed from all species but at a much slower rate than its adsorption.

Lim, R.P. (1980) Population changes of some aquatic invertebrates in ricefields. *Trop. Ecol. & Develop.*: 971-980.

*Summary:* The effects of pesticide application on the aquatic invertebrate community in ricefields was studied over two growing seasons. A total of thirty-nine taxa were collected over the two growing seasons. The dominant groups were

the nematodes, ostracods, conchostracans, ephemeropterans, hemipterans and dipterans which comprised an average of 93 percent of the total fauna. In the plots that were untreated with pesticides nematodes, hemipterans and dipterans dominated while in plots treated with pesticides ostracods, dipterans and conchostracans predominated. Temporal changes, community structure and population of the invertebrate community were affected not only by pesticide application but by ploughing, fertilization and transplanting, and the development of aquatic macrophytes. Heterogeneity decreased with the abovementioned perturbations. Only the application of the carbofuran had any significant effect in decreasing the invertebrate population. Overall the population was higher in the pesticide treated plots. This was due to inter alia to the rapid recruitment of ostracods.

Lukowski, A.B., Ligowski, R. (1987) Cumulation of chloroorganic insecticides by Antarctic marine diatoms. *Pol. Polar. Res.* 8(2): 167–178.

*Summary:* In Antarctic summer 1983/84 samples of planktonic and attached diatoms were collected in the Admiralty Bay (King George Island, South Shetland Islands) as well as samples of planktonic diatoms in the region of South Orkneys, Drake Passage and Bransfield Strait (BIOMASS- SIBEX Project). Using gas chromatography Residues of chloroorganic pesticides, namely the compounds of the DDT group and HCH isomers were determined. It was found that the highest values of the content of these compounds occurred in attached diatoms coming from areas continuously washed with water from the melting glacier, in planktonic diatoms from the samples of the Admiralty Bay and from strongly glaciated regions. A hypothesis that put forward that along with the direct atmospheric transport the release of the deposits of these compounds from ice and glaciers during their melting is an additional source of input of chloroorganic biocides into Antarctic waters. Diatoms are good indicators of this process.

Lundkvist, I. (1970) Effect of two herbicides on nitrogen fixation by blue-green algae. *Svensk. Botanisk. Tidskrift.* 64(4): 460–461. (NC)

Maharana, R.K., Dash, P.I., Padhi, S.B., Padhi, S.P. (1986) Effect of some pesticides on two nitrogen fixing blue green algae. *Geobios* (Jodhpur) 13(5): 185–188.

*Summary:* Effect of carbofuran, diuron and acephate was observed on nitrogen fixing blue green algae, *Westiellopsis prolifica* and *Anabaena* sp. These were more sensitive to diuron in comparison to others.

Mallipudi, L.R., Gleason, F.K. (1989) Characterization of a mutant of *Anacystis nidulans* R2 resistant to the natural herbicide, cyanobacterin. *Plant Sci.* (Shannon) 60(2): 149–154.

*Summary:* Cyanobacterin, a secondary metabolite produced by the cyanobacterium, *Scytonema hofmanni*, inhibits electron transport at a site in photosystem II. It was previously shown that a DCMU-resistant mutant of *A. nidulans* R2 was still susceptible to cyanobacterin (Gleason et al., *Plant Science*, 46 (1986) 5–10). Apparently, cyanobacterin acts at a site different from that of DCMU and similar PS II inhibitors. To confirm this conclusion, a cyanobacterin-resistant strain of *A. nidulans* R2 was produced by nitrosoguanidine mutagenesis and selected by growth in the presence of 4.7 M cyanobacterin. Hill activity in mutant thylakoids was compared to that of the wild type membranes in the presence of ferricyanide and silicomolybdate as electron acceptors. Photosynthetic electron transport in the mutant membranes shows a high degree of resistance to cyanobacterin in both reactions. In contrast, the mutant exhibits the same susceptibility to DCMU inhibition as the wild type R2. Cyanobacterin acts at a unique site, inhibiting electron flow from quinone-A to quinone-B.

Mallison, S.M., Cannon, R.E. (1984) Effects of pesticides on cyanobacterium *Plectonema boryanum* and cyanophage LPP-I. *Appl. Environ. Microbiol.* 47(44): 910–914.

*Summary:* Cyanobacterium *Plectonema boryanum* IU 594 and cyanophage LPP-1 were used as indicator organisms in a bioassay of 16 pesticides. Experiments such as spot tests, disk assays, growth curves, and one-step growth experiments were used to examine the effects of pesticides on the host and virus. Also, experiments were done in which host or virus was incubated in pesticide solutions and then assayed for PFU. *P. boryanum* was inhibited by four herbicides: 3-(3,4-dichlorophenyl)-1,1-dimethylurea (DCMU), 1,1-dimethyl-3-(m-fluoromethyl) urea (Huometeron), 2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine (Atrazine), 2-(ethylamino)-4-(isopropylamino)-6-(methylthio)-s-triazine (Ametryn). One insecticide, 2-methyl-2-(methylthio)-propionaldehyde 0-1(methylcarbamoyl)oxime (Aldicarb), also inhibited the cyanobacterium. Two insecticides inactivated LPP-1, 0,0-dimethyl phosphorodithioate of diethyl mercaptosuccinate (malathion) and Isotox. Isotox is a mixture of three pesticides: S-[2-(ethylsulfinyl)ethyl]0,0-dimethyl phosphorothioate (Metasystox-R), 1-naphthyl methylcarbamate (Sevin) and 4,4'-dichloro- $\alpha$ -(trichloromethyl) benzhydrom (Kelthane). Two pesticide-resistant strains of *P. boryanum* were isolated against DCMU and Atrazine. These mutants showed resistance to all four herbicides, which indicates a relationship between these phototoxic chemicals.



The results indicate that *P. boryanum* may be a useful indicator species for phototoxic agents in bioassay procedures.

Maloney, T.E., Palmer, C.M. (1956) Toxicity of six chemical compounds to thirty cultures of algae. *Water Sewage Works* 103: 509. (NC).

Mathur, R., Saxena, D.M. (1986) Effect of hexachlorocyclohexane (HCH) isomers on growth of, and their accumulation in, the blue-green alga *Anabaena* sp. (ARM 310). *J. Environ. Biol.* 7(4): 239–252.

*Summary:* The different isomers of HCH affected the growth of *Anabaena*, the beta-HCH was the most toxic of all the isomers of HCH and alpha-HCH, the least. The different isomers of HCH get accumulated to varied extent in the alga under similar experimental conditions. The maximum accumulation of delta-HCH was 13 ppm while that of gamma-HCH was only 0.62 ppm.

Maule, A., Wright, S.J.L. (1983) Physiological effects of chlorpropham and 3-chloroaniline on some cyanobacteria and a green alga. *Pest. Biochem. Physiol.* 19: 196.

*Summary:* Sublethal concentrations of the herbicide chlorpropham caused marked changes in a green alga and some cyanobacteria. Herbicide-treated cells of *Chlamydomonas reinhardtii* were enlarged, contained numerous nuclei and starch bodies, and were surrounded by multilayered envelopes. The herbicide altered the pigmentation of *Tolypothrix tenuis* by disturbing the relative amounts of the phycobiliproteins c-phycoerythrin and c-phycocyanin. Photosynthesis in *Anacystis nidulans* and *C. reinhardtii* was inhibited by chlorpropham and the herbicide also reduced the rate of nitrogen fixation by *Anabaena cylindrica*. 3-Chloroaniline, a metabolite of chlorpropham, was relatively nontoxic.

Maule, A., Wright, S.J.L. (1984) Herbicide effects on the population growth of some green algae and cyanobacteria. *J. Appl. Bacteriol.* 57(2): 369–379.

*Summary:* Six herbicides were tested for their effects on the population growth of a range of green algae and cyanobacteria by an easily replicated low-volume liquid culture technique using Repli-dishes. Diuron, propanil and atrazine were most inhibitory. Chlorpropham was more inhibitory to green algae than to cyanobacteria. The effects of chlorpropham and 3-chloroaniline, a metabolite, on populations of the cyanobacterium *Anacystis nidulans* and the alga *Chlamydomonas reinhardtii* were monitored in larger scale batch cultures. Both compounds reduced the growth rate although in some cases there was partial

recovery. 3-Chloroaniline was less inhibitory than the parent herbicide chlorpropham.

*Notes:* *In vitro* experiment with seven green algae and six BGA, Chlorpropham: EC<sub>50</sub> ranged from 15 to 40 ppm for BGA and 2 to 10 ppm for eukaryotic algae. Diuron: EC<sub>50</sub> values were lower than 0.6 ppm in all cases; Propanil EC<sub>50</sub> values ranged from 0.1 to 2.65 ppm; Atrazine: EC<sub>50</sub> values ranged from 0.06 to 5.4 ppm; Glyphosate: EC<sub>50</sub> values ranged from 70 to 600 ppm; MCPA: EC<sub>50</sub> values ranged from 90 to 300 ppm.

McCann, A.E., Roy Cullimore, D. (1979) Influence of pesticides on the soil alga flora. *Res. Rev.* 72: 1–31.

*Summary:* The soil algae probably form between four and 27 percent of the total microbial biomass in the soil and appear to fluctuate considerably with the changes in the soil's environment. These algae contribute in a very definite way to the carbon and nitrogen cycles in the soil and possibly also to the phosphorus cycle, but quantification of their roles in this cycle has yet to be firmly established. A survey of the literature for *in vivo* and *in vitro* studies on the effects of pesticides on soil algae reveals that most work has been performed using herbicides *in vitro* studies on a very selected range of algae. In reviewing these studies, the most damaging pesticide group affecting the soil algae are those herbicides which directly interfere in the photosynthesizing mechanisms of plants. Given the state of knowledge at this time, two techniques (slide implantation and soil dilution) have been recommended for the *in vivo* and *in vitro* studies of existing and new pesticides which could be applied to the soil. Some concern was expressed about the lack of information on possible synergistic effects of adding surfactants to pesticide mixtures. It was noted that much more research needs to be undertaken on the monitoring of the activity of soil algae as well as on the quantification of population and its components.

*Notes:* Bibliographic review with ninety references.

Megharaj, M., Prabhakara Rao, A., Rao, A.S., Venkateswarlu, K. (1990) Interaction effect of carbaryl and its hydrolysis product, 1-naphthol, towards three isolates of microalgae from rice soils. *Agric. Ecosys. Environ.* 31: 293–300.

*Summary:* Carbaryl and its major hydrolysis product, 1-naphthol, were applied singly and together, at equal concentrations, to a green unicellular alga, *Chlorella vulgaris*, and two cyanobacteria, *Synechococcus elongatus* and *Nostock linckia*. The effect on cell number, chlorophyll a and total protein content were assessed. The toxicities of carbaryl and 1-naphthol towards *C. vulgaris* were similar while carbaryl was more toxic than 1-naphthol towards the cyanobacteria. The

cyanobacteria were generally more sensitive to the combinations of the toxicants. Carbaryl and 1-naphthol, at different concentrations, interacted significantly, yielding either additive or synergistic responses. All the concentrations tested in combination gave a synergistic action towards the growth and nitrogen-fixing activity of *N. linckia*.

Megharaj, M., Prabhakara Rao, A., Venkateswarlu, K., Rao, A.S. (1987) Toxicity of *Parthenium hysterophorus* extracts to *Chlorella vulgaris* and *Synechococcus elongatus*. *Plant Soil* 103(2): 292–294.

*Summary:* Aqueous extracts from leaf or inflorescence of *Parthenium hysterophorus* were either algistatic or algicidal to *Chlorella vulgaris* and *Synechococcus elongatus*. Root extract, however, enhanced the growth of the two algae, but a 2.5 percent level was algistatic to *S. elongatus*.

Megharaj, M., Venkateswarlu, K., Rao, A.S. (1986) Growth response of four species of soil algae to monocrotophos and quinalphos. *Environ. Pollut. Ser A Ecol. Biol.* 42(1): 15–22. (NC)

*Summary:* *Scenedesmus bijugatus*, a green alga, and three blue-green algae (Cyanobacteria), *Synechococcus elongatus*, *Nostoc linckia* and *Phormidium tenue* all isolated from a black soil, were tested for their growth response to monocrotophos and quinalphos, using either cell number or chlorophyll a as toxicity criteria. Monocrotophos was significantly toxic above 20 g/ml to *S. bijugatus*, but enhanced the growth of *S. elongatus*, at all concentrations (5 to 100 g/ml) tested. At 100 g/ml, monocrotophos was toxic to *N. linckia* and at 50 and 100 g/ml, to *P. tenue*, but lower concentrations increased the growth of these two algae significantly. Quinalphos above 5 or 10 g/ml exhibited an algistatic effect on *S. bijugatus*, *S. elongatus* and *N. linckia* and was algicidal to them at the higher concentrations. Quinalphos, however, resulted in a significant enhancement in the growth of *P. tenue* at all concentrations.

Megharaj, M., Venkateswarlu, K., Rao, A.S. (1987) Influence of cypermethrin and fenvalerate on a green alga and three cyanobacteria isolated from soil. *Ecotoxicol. Environ. SAF* 14(2): 142–146.

*Summary:* The effects of two pyrethroid insecticides, cypermethrin and fenvalerate, on a green alga (*Scenedesmus bijugatus*) and three species of cyanobacteria (*Synechococcus elongatus*, *Nostoc linckia*, and *Phormidium tenue*), all isolated from a black cotton soil, were studied using either cell number or chlorophyll a as toxicity criterion. All the four species were either unaffected or stimulated at 5 g/ml. Of the two insecticides, cypermethrin, at 10 to 50 g/ml,

inhibited *S. bijugatus* while these concentrations stimulated or only slightly inhibited the growth of *S. elongatus*. There was a significant inhibition in the growth of *S. bijugatus* and stimulation in *S. elongatus* with 10 to 50 g/ml fenvalerate. The growth of *N. linckia* was enhanced by both insecticides while *P. tenue* was significantly affected.

Megharaj, M., Venkateswarlu, K., Rao, A.S. (1988a) Effect of insecticides and phenolics on nitrogen fixation by *Nostoc linckia*. *Bull. Environ. Contam. Toxicol.* 41: 277–281. (NS)

*Notes:* *In vitro* test of monocrotophos, quinalphos, cypermethrin, and fenvalerate at concentrations ranging from 5 to 100 ppm. Results do not include a control with no pesticide.

Megharaj, M., Venkateswarlu, K., Rao, A.S. (1988b) Tolerance of algal population in rice soil to carbofuran application. *Current Science* 57(2): 100–103. (NS)

*Notes:* Experiment on 20 g soil samples in test tubes. Ten and twenty days after exposure to various doses of furadan, soil algae were enumerated by MPN. Results show that at recommended field level, carbofuran had no detrimental effect on algal populations, BGA were favored by the pesticide application.

Megharaj, M., Venkateswarlu, K., Rao, A.S. (1989a) Effects of carbofuran and carbaryl on the growth of a green alga and two cyanobacteria isolated from a rice soil. *Agric. Ecosys. Environ.* 25(4): 329–336.

*Summary:* Two methylcarbamate insecticides, carbofuran and carbaryl, were assessed for their effects on a green unicellular alga, *Scenedesmus bijugatus*, and two cyanobacteria, *Synechococcus elongatus* and *Nostoc linckia*, all isolated from a rice soil. In laboratory studies, both insecticides up to 20 g/ml concentration significantly increased the cell number of *S. bijugatus*. *Synechococcus elongatus* was highly sensitive, 5 g/ml of each chemical being lethal. Concentrations, up to 20 or 50 g/ml, of the two insecticides initially increased chlorophyll a in *N. linckia* significantly, which again led to a subsequent inhibition. In general, carbaryl was more toxic than carbofuran to all the test organisms.

Megharaj, M., Venkateswarlu, K., Rao, A.S. (1989b) Interaction effects of insecticide combinations towards the growth of *Scenedesmus bijugatus* and *Synechococcus elongatus*. *Plant Soil* 114: 159–163.

*Summary:* The interaction effects of insecticide combinations involving an organophosphate (monocrotophos or quinalphos) and a pyrethroid (cypermethrin

or fenvalerate) were determined on the growth of *Scenedesmus bijugatus* (unicellular green alga) and *Synechococcus elongatus* (unicellular cyanobacterium). In general, an organophosphate and a pyrethroid in combinations interacted additively, antagonistically, and synergistically on the growth of the two phototrophic microorganisms. However, combinations of quinalphos and cypermethrin or fenvalerate yielded additive interaction response in only *S. bijugatus*.

Mehta, R.S., Hawxby, K.W. (1979) Effects of simazine on the blue-green alga *Anacystis nidulans*. *Bull. Environm. Contam. Toxicol.* 23: 319–326. (NS)

*Notes:* Study of the effects of simazine on RNA and ultrastructure of *Anacystis*.

Mikhailova, E.I., Kruglov Yu, V. (1973) Effect of some herbicides on soil algi flora. *Pochvovedenie* 8: 81. (NC)

Minervini Ferrante, G., Battino Viterbo, A., Bisiach, M. (1974) Agar plate technique for potential algicide screening. *Riso* 23: 13–18.

*Summary:* A method used for the evaluation of the eradicator action of fungicidal chemicals was adapted for the *in vitro* evaluation of compounds with algicidal activity. In this paper a series of tests using some low toxicity chemical compounds (2-dichloroacetamide-3-chloro- 1, 4-naphtoquinone, Chlortalonil, Dichlorophen) against two cyanophyta commonly infesting Italian rice-fields, *Oscillatoria* sp. and *Cylindrospermum* sp., are reported. The method appears to be effective giving prompt and reproducible results. The experimental data were statistically analyzed in order to evaluate the significant differences between the dosages. The results obtained confirm the high activity of the naphtoquinone derivative which appears to be a possible alternative to the use of the tin compounds.

Mishra, A.K., Pandey, A.B., (1989) Toxicity of three herbicides to some nitrogen-fixing cyanobacteria. *Ecotoxicol. Environ. SAF* 17(2): 236–246.

*Summary:* The effects of some common ricefield herbicides, such as 2,4-dichlorophenoxyacetic acid (2,4-D), Machete, and Saturn, on the paddy field nitrogen-fixing cyanobacteria *Nostoc linckia*, *Nostoc calcicola*, *Nostoc* sp., and *Anabaena doliolum* were studied. These cyanobacteria were found to be more tolerant to 2,4-D (lethal doses 1,500–2,000 g/ml) than to Machete and Saturn (lethal doses 6–8 g/ml). The effects of these three herbicides on some physiological processes of *N. linckia* were studied. The 2, 4-D stimulated the growth and nitrogen fixation up to 100 g/ml concentration (a dose higher than the field

dose, i.e., about 40 g/ml), recommended for field application. However, with Machete and Saturn this type of stimulation was not observed even at lower concentrations. Similarly, the uptake of nutrients, such as  $\text{NO}_3^-$  and  $\text{NH}_4^+$  was also inhibited by Machete and Saturn. However, 100 g/ml 2,4-D stimulated the uptake of  $\text{NO}_3^-$  but not of  $\text{NH}_4^+$  higher doses of 2,4-D inhibited the uptake of both nutrients. Factors such as pH, organic carbon sources (glucose and acetate), and amino acids were found to regulate the toxicity of all three herbicides to *N. linckia*. Lower pH enhanced the toxicity of all three herbicides, whereas higher pH (up to 9.0) lowered it. Glucose and acetate (each 500 g/ml) protected against the toxicity of 2,4-D and Saturn, but not against Machete. Whereas glutamine, arginine, serine, and tryptophan conferred upon *N. linckia* a greater protection against the toxicity of all three herbicides, methionine did not do so, and the presence of methionine with herbicide in the culture medium resulted in greater toxicity to *N. linckia* than that in the presence of the herbicide alone.

Moore, R.B. (1967) Algae as biological indications of pesticides. *J. Phycol.* 3 (Suppl): 4. (NC)

Morar, S.N. (1970) Development of algae in ricefields in connection with application of herbicides [in Russian]. In *Vazhneishie Probl. Selekt. Orosheniia Risa*, Moskva, Kolos: 217–219. (NS)

Morton, L.H.G., Lovell, M.L., Mitchell, A.F. (1984) The effect of maceration on filamentous algae used for the testing of algicidal compounds. *Int. Biodeterior* 20(1): 33–36.

*Summary:* An account is presented of the effect of maceration on the growth on solid media of two filamentous test algae [*Trentepohlia* and *Oscillatoria*] known to foul paint surfaces. Maceration had little effect on algal viability, showing that macerates of filamentous algae may be used in algicidal assay procedures. An assay procedure using filter paper discs impregnated with Nuodex 87 is outlined.

Mukherji, S.K. (1968) Chemical control of algae in West Bengal paddy fields. *World Crops* 20(1): 54–55. (NS) (see Mukerji and Laha, 1979)

Mukherji, S.K. (1970) Further studies on the chemical control of algal weeds. *World Crops* 22(6): 287–288. (NC) (cited in Das, 1976)

Mukherji, S.K. (1972) Use of pentachlorophenol as an algicide in paddy fields in West Bengal. *Weed Res.* 12(4): 389–390. (NS)

Mukherji, S.K., Laha, J.N. (1979) Effect of different chemicals used as algicides for control of algal weeds in lowland aman paddy field of coastal belt of West Bengal. *Pesticides* (July) 79: 54–55.

*Summary:* In a field trial for a year, application of Machete 5 percent granules (at 50 kg/ha) copper sulphate (at 12.50 kg/ha) as well as Dithane M-45 (at 6.25 kg/ha) were found most effective in controlling algae in lowland paddy field and they also thus gave increased grain yields. Lasso did not prove to be an effective algicide.

*Notes:* The authors report significant increase in yield when controlling *Chara* and *Nitella* by various algicides. Machete, copper sulphate, and Dithane controlled algae and increased yield by 47 percent, 26 percent, and 24 percent respectively. Lasso had no effect no algae and yield.

Mukherji, S.K., Ray, B.K. (1966) Algal weeds of paddy fields of coastal West Bengal and their control by a new chemical. *Z. Pfl. Krankheit u. Pfl. Schutz.* 73: 35–40. (NC) (cited in Das, 1976).

Mukherji, S.K., Sengupta, S.K. (1964) Control of algal weeds in paddy fields of West Bengal, India. *FAO Plant Protection Bull.* 12: 129–130. (NC) (cited in Das, 1976)

Muzafarova, D.A., Kuchkarova, M.A. (1971) Effect of herbicides on the flora of rice paddies. *Biol. Ekol. Georg. Sporovykh. Rust. Srednei. Azii.* 145–146. (NC)

*Notes:* In Russian with no English summary.

Noll, M., Bauer, U. (1973) Rapid sensitive herbicide bioassay by inhibition of trichome-migration of blue-green algae. *Zbl. Bakt. Hyg., 1 Abt. Orig B* 157: 178. (NC)

Padhy, R.N. (1985) Cyanobacteria and pesticides. *Res. Rev.* 95: 1–44.

*Summary:* Most of the studies of effect of pesticides on cyanobacteria are carried out in the laboratory. *Anabaena* was more sensitive to DDT compared to *Anacystis microcystis*. In field conditions BHC stimulated growth of cyanobacteria by suppressing green algae. *Cylindrospermum* was most sensitive to BHC. *Agmenellum* was inhibited by low concentrations of endrin, but not *Anacystis*. Of course, *Agmenellum* had a better tolerance towards aldrin and dieldrin compared to *Anacystis*. Parathion at levels 1 to 5 ppm was harmless to N<sub>2</sub>-fixing cyanobacteria in fields. Diazinon inhibited growth of cyanobacteria at

levels above 400 ppm. Carbaryl inhibited growth of *Cylindrospermum* and *Nostoc* at 120 ppm; carbofuran was growth stimulatory at 25 ppm and was completely toxic to these two genera at 3,000 and 2,000 ppm, respectively. The bloom of *Microcystis* was cleared by dichlone at a higher level (30 to 55 ppm) compared to the levels used for elimination of other cyanobacteria from fish ponds. Zineb inhibited growth of *Cylindrospermum* and *Nostoc* at 30 to 35 ppm in laboratory cultures but permitted growth of the majority of ricefield cyanobacteria at 100 kg/ha in field conditions. Ziram (2 to 6 ppm) eliminated  $N_2$ -fixing cyanobacteria in laboratory cultures. In field conditions, unlike other cyanobacteria, *Tolypothrix* and *Anacystis* tolerated 200 kg/ha Ceresan. In general, *Tolypothrix* had a higher tolerance capacity towards brassicol, bavistin, and fytolan. *Microcystis* and *Nostoc* can tolerate 2,4-D better compared to other genera. *Anacystis* had better tolerance capacity towards propazine and phenylurea herbicides (diuron and cotoron). *Aulosira* is reported to be most sensitive to most of the herbicides. *Tolypothrix* tolerated the highest level (below 18 ppm) of propanil. Light was essential to the herbicidal activity of the bipyridyl herbicides diquat and paraquat. Prometryn and symetryn had no adverse effect on cyanobacteria when applied in field conditions. In general, the cyanobacteria were reported to be sensitive to the antibiotics, particularly *Plectonema* to virginiamycin, and were less affected by copper sulfate. Morphometric studies with cells of *Plectonema* and *Anabaena* indicated the toxic actions of heavy metals in ultrastructure. Sodium chloride was reported to increase the toxicity of DDT to *Anacystis*; calcium had a beneficial effect in the reversal of this toxicity. Presence of combined nitrogen sources in growth media also had a toxicity-reducing effect on  $N_2$ -fixing forms. Fertilizers like urea and superphosphate reduce the toxicity of carbamate pesticides to  $N_2$ -fixing cyanobacteria (*Cylindrospermum* and *Nostoc*). In all available reports, there is a reduction in  $N_2$  fixation in cyanobacteria by most pesticides. Naphthalene is oxidized by *Oscillatoria* to 1-naphthol. BHC, aldrin, DDT, carbaryl, carbofuran, Ziram, Zineb, Mancozeb, and parathion, etc. are reported to be taken up by cyanobacteria. The possibility of use of cyanobacteria in waste water is indicated. Cyanobacteria are not widely used for pesticide bioassay; trichome migration in *Phormidium* was seen to be an effective method for this purpose. Mutagenicity testing has been done with cyanobacteria for very few pesticides which are not known yet to induce non- $N_2$ -fixing mutants in cyanobacteria. Pesticide-resistant mutants of  $N_2$ -fixing forms (that are isolated) are indicated to be useful in maintenance of soil fertility and can be introduced into agriculture. It is discussed that there is difficulty in enumeration of cyanobacterial growth in field conditions.

Pal, R., Chatterjee, P. (1987) Algicidal action of diuron in the control of *Chara*, a rice pest. *Proc. Indian Acad. Sci. Plant. Sci.* 97(4): 359–363.



*Summary:* Diuron, a common algicide, was used in controlling the oospore formation of *Chara* species. Ten ppm solution of the chemical was found effective in controlling the sperm production in case of *Chara corallina* within 72 h of treatment. Fifty ppm solution was toxic to *Chara zeylanica* within 24 h of treatment. The threshold concentration (10–50 ppm) obtained did not affect the germination and vegetative growth of the rice seedlings since the transient effect was quickly reversed within a short time.

Palmer, C.N., Maloney, T.E. (1955) Preliminary screening for potential algicides. *Ohio J. Sci.* 55: 1. (NC)

Pande, A.S., Rekha, Sarkar, Krishnam-Oorthi, K.P. (1981) Toxicity of copper sulfate to the alga *Spirulina platensis*, and the ciliate *Tetrahymena pyriformis*. *Indian J. Exp. Biol.* 19(5): 500–502.

*Summary:* Effects of different concentrations of copper sulphate (as  $\text{Cu}^{2+}$ ) on *S. platensis* and *T. pyriformis* were studied to determine the response of these fish food chain organisms to Cu. Aligicidal and aligistatic responses were determined in *S. platensis*. Further experiments were done to study the toxic effect of copper sulphate to *T. pyriformis* which will help to know the effective dose that will affect the simplest organism at the base of the fish food chain. Lethal, sublethal and  $\text{LC}_{50}$  (50 percent mortality in a specific period) values were recorded.

Pandey, A.K. (1985) Effects of propanil on growth and cell constituents of *Nostoc calcicola*. *Pest Biochem. Physiol.* 23: 157–162.

*Summary:* The ricefield herbicide, propanil, was toxic to the  $\text{N}_2$ -fixing cyanobacterium *Nostoc calcicola*. A decrease in growth was observed with the increasing concentrations of propanil, 30 g/ml being lethal. Since toxicity of the herbicide could be reversed by exogeneous supplementation of assimilable organic carbon glucose, it is suggested that carbon fixation was sensitive to the herbicide. The herbicide inhibited heterocysts differentiation and nitrogen fixation. There was a rapid decrease in total protein, nucleic acids (DNA, RNA), and carbohydrate content accompanied by a loss of photosynthetic pigments. The phycocyanin: chlorophyll a ratio showed positive correlation with increased dosages of the herbicide, suggesting the inhibition of chlorophyll a.

Pandey, A.K. (1987) pH dependent Saturn toxicity and nitrogen fixation of *Nostoc calcicola*. *Acta Bot. Indica* 15(2): 231–235.

*Summary:* The effect of pH on the toxicity of the ricefield herbicide Saturn was studied on the nitrogen-fixing cyanobacterium *Nostoc calcicola* under cultural conditions. The cyanobacterium survive in a wide range of pH (7–10). A progressive increase in the growth yield of the cyanobacterium was observed with increasing pH (7–10), attaining optimum at pH 9. The toxicity of the herbicide was reduced by raising pH (7–10) of the external medium. The elevated concentrations of the herbicide (2 to 4 g/ml) permitted growth and cell multiplication at or above pH 9 and the extremely low concentration (0.5 g/ml), reduced the growth of the cyanobacterium at neutral pH (7), showed a slight stimulation in growth at high pH (9–10). Heterocyst differentiation and nitrogen fixation was affected by the higher concentrations of Saturn while this effect was partially relieved by raising pH (7–10) of the medium with optimal values at pH 9. The results suggest that high pH are most effective in reducing the herbicide toxicity compared to neutral or low pH.

Pandey, A.K., Srivastava, V., Tiwari, D.N. (1984) Toxicity of the herbicide Stam f-34 (propanil) on *Nostoc calcicola*. *Z. Allg. Mikrobiol.* 24(6): 369–376.

*Summary:* The biological effect of the post-emergence ricefield herbicide Stam f-34 on the N<sub>2</sub>-fixing cyanobacterium (blue-green alga) *Nostoc calcicola* has been studied under cultural conditions. The herbicide caused an inhibition of the N<sub>2</sub>-fixing growth of the alga which was concentration-dependent and lethal at 30 g/ml. Both glucose and acetate quite efficiently reversed the inhibitory action of Stam f-34 even when it was present at a lethal dose. Also, an addition of the amino acids arginine, aspartic acid, serine, threonine and glutamine readily reversed the toxic effects of Stam f-34 even at lethal concentrations of herbicide (except glutamine). Low pH values enhanced the toxicity while high pH levels lowered the toxicity of herbicide to the alga. The herbicide was not mutagenic since it did not induce in the alga mutations to streptomycin and methylamine resistance.

Pandey, A.K., Tiwari, D.N. (1986) Action of 2, 4-Dichlorophenoxyacetic acid on *Nostoc linckia*: impact of glucose and tryptophan. *Folia Microbiol.* 31(1): 50–55.

*Summary:* 2,4-Dichlorophenoxyacetic acid (2,4-D) stimulated growth and heterocyst differentiation of *Nostoc linckia* in nitrogen-free medium at lower concentrations (100 g/ml) while its higher concentrations inhibited both processes and 1,500 g/ml provided to be lethal. Dry mass and specific growth rate of the alga declined with increasing concentration of 2,4-D in the range of 100–1,500 g/ml. Glucose slightly increased the heterocyst frequency without any lag in their differentiation. Tryptophan promoted growth of the alga and formation

of heterocysts (nearly three-fold). Tryptophan (50 g/ml) complex medium with 1 mg 2,4-D/ml did not produce mature heterocysts. The filaments were fragmented at the point of heterocyst development and detached heterocysts germinated in situ. Glucose and tryptophan protected the alga, its growth and heterocyst differentiation even at the lethal concentration of the herbicide.

Pandey, K.D., Kashyap, A.K. (1986) Differential sensitivity of three cyanobacteria to the ricefield herbicide Machete. *J. Basic Microbiol.* 26(7): 421–428.

*Summary:* The effect of the ricefield herbicide Machete (2-chloro-2'6' -diethyl-N-(Butoxy methyl) acetanilide) on the growth and cell composition of *Anacystis nidulans*, *Nostoc muscorum* and *Anabena doliolum* was investigated. Growth of these cyanobacteria was completely inhibited at 2.5, 5.0 and 20 µg/ml, respectively, while a slight stimulation of growth was observed at lower concentrations. Stimulation of cyanobacterial growth in the presence of low concentrations of Machete was associated with an increase in the cellular levels of phycobilins and RNA while there was little impact on the levels of chlorophyll a and DNA. Photosynthetic pigments were degraded at lethal concentrations. The toxicity of the herbicide towards *N. muscorum* and *A. doliolum* could be reversed by supplementing the growth medium with either nitrate, nitrite or ammonia. This did not apply for *A. nidulans*. It is suggested that Machete inhibited N<sub>2</sub> fixation in the former two strains while nutrients availability was affected in the latter strain. In either case death, of the organisms was most likely due to nitrogen starvation.

Panigrahy, K.C. (1984) Physiological and genetical effect of pesticides on blue-green algae: effect of carbamate pesticides. Ph.D. dissertation, Berhampur University, India. (NC)

Paraschiv, M., Serbanescu, E., Popovici, G.h, Djendon, C. (1972) Algicide action of chemical substances on blue green algae. *Rev. Roum. Biol. Ser. Bot.* 17: 195. (NC)

Patnaik, S., Ramachandran, V. (1976) Control of BGA with simazine in fish ponds. Pages 285–291 in *Aquatic weeds in Southeast Asia*, Varshney, C.K., Rzoska, J. (eds.), W Junk B.V. La Hague pub.

*Summary:* The paper describes field experiments conducted for controlling *Microcystis* bloom with simazine. The chemical was applied to the pond surface by means of foot pump sprayer at 200–400 l/ha. The bloom disappeared in 16–20 days with 0.25–0.75 ppm active simazine. The observations indicated that application of the chemical was not found to cause any toxicity to fish

population. It is also non-toxic to zooplankton and other animal life in the pond. The cost of clearance worked out between Rs. 270—toRs.438/ha. The dissolved oxygen in the treated pond may drop as a consequence of the decaying organisms which might cause distress to fish but the problem can be overcome by suitable precautionary measures.

Pattnaik, H., Prakash Rao, M. (1982) Effect of pesticides on growth and nitrogen-fixation of blue-green algae. Page 670 in *Proceedings of a National Symposium on Biological Nitrogen Fixation*, New Delhi.

*Summary:* The investigation is aimed at determining the effect of certain pesticides on growth and N<sub>2</sub> fixing ability of two blue-green alga, *Westiellopsis prolifica* and *Anabaena cylindrica* commonly found in the ricefields of Orissa. Different doses of pesticides have been used and it was found that at lower concentrations of pesticides the growth and N<sub>2</sub> fixing capacity of BGA are stimulated. The studies on the reversal of toxicity of pesticides using nitrogen carbon and phosphorus resources showed that, at certain critical concentrations of pesticides, the above resources can modify the toxic effects.

Pillay, A.R., Tchan, Y.T. (1970) The use of algae for the bioassay and study of tri-allate (herbicides). *Soil Biol.* 12: 20. (NC)

Pillay, A.R., Tchan, Y.T. (1972) Study of soil algae. VII. Adsorption of herbicides in soil and prediction of their rate of application by algal methods. *Plant Soil* 36: 571–594.

*Summary:* Algal techniques were used to study the soil factors affecting the toxicity of herbicides. It was found that the organic matter adsorbed eighteen times more herbicide than clay. The inherent phytotoxicity of different herbicides was tested by these methods and the results obtained compared favorably to those of higher plants. The order of toxicity as tested by algae was: diuron > neburon > monuron > atrazine > simazine > atratone. The prediction of application rates of diuron and simazine by algal methods was tested in the field with wheat as cereal crop. The data obtained testified that the predictions were correct and better than the commercial recommendation. Good chemical control of weeds was achieved by herbicide at the early stage of crop growth. At later stages of crop development the toxicity of the chemical was reduced to insignificance and the crop plants were then capable to compete successfully against the emerging weeds. Thus a biological weed control was obtained. Such combined chemical-biological weed control technique should be regarded as the most desirable practice in agriculture.

Planas, D., Patrick, Healey, F. (1978) Effects of arsenate on growth and phosphorus metabolism of phytoplankton. *J. Phycol.* 14(3): 337–341.

*Summary:* The response to arsenate in growth and phosphate uptake by five algae in culture varied considerably. The growth rates of *Melosira granulata* var. *angustissima* O. Mull. and *Ochromonas vallesiaca* Chodat were depressed by 1 M arsenate. *Chlamydomonas reinhardtii* Dang. required 10 M for the same degree of depression, while the growth rates of *Cryptomonas erosa* Ehr. and *Anabaena variabilis* Kutz. were unaffected up to 100 M. However, following depletion of phosphate, cultures of the latter two algae began to die at the higher concentrations of arsenate tested. Growth of *C. reinhardtii* in the presence of 35 M arsenate resulted in characteristics of P deficiency. Comparison of rates of photosynthesis, respiration, and phosphate uptake between cultures of *C. reinhardtii* which had grown in the presence and absence of arsenate showed little evidence after 16 doublings that it had adapted to arsenate.

Prasad, A.B., Samanta, R., Vishwakarma, M.L., Vaishampayan, A. (1986) Biological effects of a mercury fungicide on a nitrogen-fixing blue-green alga *Nostoc muscorum*: Isolation and preliminary characterization of a mercury-resistant mutant. *New Phytol.* 102(1): 45–50.

*Summary:* Mercuric chloride, which is used as a fungicide in tropical paddy-fields, inhibits growth (in N<sub>2</sub>, i.e. molecular nitrogen, and 5 mM KNO<sub>3</sub> media) and heterocyst formation (in N<sub>2</sub> medium) in the blue-green alga *Nostoc muscorum* at a concentration of 0.3 g/ml and above. These inhibitory effects were reversed on supplementation with 3 mM exogenous glucose. A mercury resistant mutant of this alga has been obtained, which is stable through repeated cell transfers in N<sub>2</sub> medium. It is suggested that a Hg-inducible protein/enzyme system is responsible for the intracellular mercury-resistance of this mutant.

Prescott, G.W. (1948) Objectionable algae with reference to killing of fish and other animals. *Hydrobiologia* 1: 1–13.

*Notes:* Contains a list of recommended doses of copper sulphate as an algicide.

Raghu, K., Macrae, I.C. (1967) The effect of the gamma isomer of benzene hexachloride upon the microflora of submerged rice soils. I. Effect upon algae. *Can. J. Microbiol.* 13: 173–180.

*Summary:* The effect of additions of the gamma-isomer of benzene hexachloride (gamma-BHC) upon algal populations in two submerged tropical rice soils was studied. Additions of the insecticide to the floodwaters of the soils at 5, 6, and 50 g/ha active compound resulted in a marked stimulation of growth of the

indigenous algae. The stimulation was attributed to the elimination by the insecticide of small animals which feed on the algae. No detrimental effect upon total algal populations was found when gamma-BHC was applied at 50 kg/ha, which is 10 times the rate recommended to control the rice stem borer. Qualitative changes were detected in the incidence of major algal groups. Blue-green algae were more abundant in treated soils whereas the green algae and diatoms were more abundant in the untreated soils. Much larger amounts of algal tissue were produced in the floodwaters treated with gamma-BHC. The possible effects of increased algal development on the fertility of the soil and the persistence of gamma-BHC in submerged soils are discussed.

Raghva Reddy, H.R. (1976) Studies on influence of pH, phosphate and pesticides on nitrogen fixation and radiocarbon assimilation by two blue green algae, M.S. thesis, University of Agricultural Sciences, Bangalore, India. (NC)

Rao, V.V., Narayana, S., Lal, R. (1987) Uptake and metabolism of insecticides by blue-green algae *Anabaena* and *Aulosira fertilissima*. *Microbios Lett.* 36( 143/144): 143–148.

*Summary:* Blue-green algae *Anabaena* and *Aulosira fertilissima* rapidly accumulated and concentrated malathion and endosulfan from the medium. The uptake was linearly related to the insecticide concentration while bioconcentration was inversely related. Besides water solubility, stereo-chemical differences between isomers of endosulfan also influenced the uptake. Malathion was not metabolized by the algae, but endosulfan was converted to endosulfan ether and endosulfan lactone.

Rath, P., Choudhury, S.B., Misra, B.N. (1987) Effects of Emisan 6 (2-methoxyethyl mercury chloride) on the growth of *Westiellopsis prolifica* Janet. *Microbios Lett.* 34(135/136): 129–134.

*Summary:* The effect of Emisan-6 on the growth rate pattern of a blue-green alga, *Westiellopsis prolifica* Janet, was studied. A drastic reduction in the growth rate occurred at high concentrations and long exposure periods. Toxicity increased with increase in the exposure period. A negative correlation existed between the growth rate and pollutant concentration. Partial recovery in growth performance occurred when *W. prolifica* was transferred to mercury-free culture medium.

Rath, P., Panigrahi, A.K., Misra, B.N. (1985) Effect of pesticides on the photosynthetic efficiency of a blue-green alga, *Westiellopsis prolifica*. *Microbios Lett.* 29( 113): 25–30.

*Summary:* The effects of the pesticides  $\text{HgCl}_2$  and Emisan-6 (MEMC) on the photosynthetic efficiency of *W. prolifica* were studied. At lower concentrations of the Hg based pesticide, a significant increase in  $\text{O}_2$  evolution occurred. With the increase in toxicant concentration and exposure period, a drastic decline was evident. The Hg based pesticide toxicity was totally dose/concentration dependent. At lower concentrations, Hg based pesticide toxicity was totally dose/concentration dependent. At lower concentrations, Hg acted as a growth regulator and at higher concentrations it acted as a growth inhibitor.

Ray, R.C., Sethunathan, N. (1988) Pesticides and nitrogen transformations in flooded soils. Vol. 2. Pages 119–142 in *Pesticides and nitrogen cycle*, Lal, R., Lal, S. (eds.)

*Summary:* It is clear from the above survey that reports on the side effects of pesticides on microorganisms and their activities in flooded soils are not consistent. Conflicting reports of the same pesticide exhibiting innocuous, inhibitory, and stimulatory effects on a specific microorganism and its activity are not uncommon in literature. Because, methodology used in many of these studies is not uniform especially with regard to the concentration of pesticide, formulation of the pesticide, the incubation conditions, sampling procedure, analytical techniques, and criteria used in evaluation of the side effects. In studies with formulations, a question arises whether the observed effects are due to the active ingredient, carrier in the formulation or synergistic interaction between the carrier and formulation, increasing the toxicity to insects. Evidently, for a meaningful conclusion, there is a need to generate data on side effects from simultaneous studies with formulated and technical or analytically pure pesticide. Again, for chemically and/or biologically unstable pesticides such as carbamate and organophosphorus groups, the observed side effects after application of parent molecule may be due to their breakdown products and not necessarily due to the parent molecule. 1-Naphthol, hydrolysis product of carbaryl, is more toxic than carbaryl to certain microorganisms and their activities. Unfortunately in the experimental design and in the interpretation of results, the role of breakdown products of specially unstable insecticides is often neglected. In majority of studies on the side effect on pesticides, data were generated under laboratory conditions using relatively high pesticide concentrations. Extrapolation of these results to actual field conditions is therefore questionable. Pure culture studies may not have much relevance since in nature a vast range of microorganisms interact with each other and the net effect on microbial community is more important than the effect on individual microorganisms. This is particularly true in transformations such as denitrification and  $\text{N}_2$  fixation, which are carried out by a myriad of taxonomically different microorganisms. Despite the inconsistency

and several differences in the reported studies, certain definite conclusions are possible. Contrary to the common belief that pesticides applied at recommended levels and intervals seldom affect, adversely or beneficially, the microbial processes, certain pesticides such as carbofuran even when applied to the soil at recommended level effected striking stimulation of  $N_2$  fixation and autotrophic oxidation of ammonium. Likewise, there is convincing evidence in support of significant interactions between pesticides in a combination, as for instance carbofuran and HCH applied at individually subtoxic levels leading to increased toxicity to nitrification. There is an urgent need to demonstrate these and other side effects of pesticides in a more complete model ecosystems comprising various biotic and abiotic components of a flooded ricefield. Such microcosm studies would help in a better understanding of the significance of the interactions of the pesticide with the microbial community in the nutrient-rich rhizosphere soil and overall impact of such interactions on soil fertility.

Rohwer, F., Fluckiger, W. (1979) Effect of atrazine on growth, nitrogen fixation and photosynthetic rate of *Anabaena cylindrica*. *Angew. Bot.* 53: 59. (NC)

Saha, K.C., Mandal, L.N., Sannigarahi, S., Brandhopadhya, S. (1982) Effect of pesticide on nitrogen fixation and chlorophyll-a development in blue-green algae *Nostoc muscorum* and *Nostoc* sp. In *Proceedings of a National Symposium on Biological Nitrogen Fixation*, IARI, New Delhi.

*Abstract:* The effect of pesticide, Phorate [O,O-diethyl S(ethylthiomethyl) dithiophosphate], containing 10 percent ingredient, on  $N_2$  fixing activity and acetone extracted chlorophyll content due to inoculation of two species of BGA *Nostoc muscorum* and *Nostoc* sp. 2, in N-free media and alluvial rice soil were investigated in laboratory experiment. The lower concentration, 5–10 g/ml, encouraged the  $N_2$  fixation and chlorophyll content over control in media.

Saha, K.C., Panigrahi, S., Bandopadhyay, S.K., Mandal, L.N. (1984) Effect of phorate on nitrogen fixation by blue-green alga. *J. Indian Soc. Soil Sci. Agric. Chem.* 32: 19–83.

*Summary:* The effect of phorate (insecticide) on  $N_2$  fixing blue-green algae, *Nostoc muscorum* and *Nostoc piscinale* was studied in liquid and soil culture systems. The fixation of  $N_2$  and chlorophyll content of these algal cultures were markedly increased by the application of insecticide at lower concentrations. *N. muscorum* was more efficient than *N. piscinale* and performed well up to 50  $\mu$ g/ml in liquid culture and at most levels (up to 250  $\mu$ g/g) of insecticide application in soil culture. The toxicity of higher concentrations of insecticide was found to be gradually reduced on prolonging the growth period of the algal species.



Higher concentrations up to 250 µg/g soil and/or/ml medium were less lethal in soil culture than in liquid medium for both the algal species.

Salama, A.M., Kobbia, L.A., Shabana, E.F. (1984) Effect of sublethal concentrations of 2,4-D on the growth, carbohydrate and nitrogen metabolism of two phytoplankton from the Nile drains (Egypt). *Egypt. J. Physiol. Sci.* 11(1/2): 111-126.

*Summary:* The axenic cultures of either *Anabaena flos-aquae* or *Phormidium fragile* were subjected to various sublethal concentrations of 2,4-D in greenhouse chambers. The dry weight gain by both organisms was stimulated at lower levels and attenuated at higher concentrations. This trend was accompanied by a concomitant similar response in chlorophyll a biosynthesis, but with minor changes in the soluble sugar contents of the two algal masses. Lower and moderate levels of the herbicide induced a significant accumulation of polysaccharides and total carbohydrate contents, a trend that was attenuated at the highest dose of 2,4-D. The nitrate uptake by both algae was stimulated, accompanied generally with more nitrogen secretion and concomitant elevation in the total nitrogen contents, but the activation rate varied with the organism. Protein synthesis was accelerated under all treatments in *Phormidium* cells, but was remarkably suppressed at lower doses in *Anabaena* and slightly increased at high concentration. It is apparent that the stimulatory and/or inhibitory effects of 2,4-D on the growth of both algae were mainly correlated with the fluctuation of carbohydrate content, rather than disturbances in nitrogen metabolism.

Salama, A.M., Kobbia, L.A., Shabana, E.F. (1985) Growth, chlorophyll a content and metabolic responses of *Anabaena flos-aquae* and *Phormidium fragile* to the herbicide dalapon. *Egypt. J. Physiol. Sci.* 12(1): 5346.

*Summary:* All concentrations of dalapon, except the highest, were generally accompanied with minor effects on the growth of dose (2700 ppm) caused a statistically significant drop in *Anabaena flos-aquae* and *Phormidium fragile*. The highest growth that was more prominent in *Anabaena*. Chlorophyll a biosynthesis was suppressed in *Phormidium* and fluctuated in *Anabaena* but was inhibited at the highest dose. Lower doses induced more accumulation of total carbohydrates, while higher levels suppressed its formation in both organisms. The nitrate uptake and total nitrogen content were stimulated by Dalapon in case of *Anabaena* but vice versa in *Phormidium*. The limited variations in the total insoluble nitrogen of *Anabaena* were mainly a result of respective changes in the other insoluble fraction and not the protein. The latter fraction, on the other hand, was accumulated in the cells of *Phormidium*.

Salem, K.G. (1980) Effect of some herbicides on nitrogen fixing blue-green algae. Ph.D. thesis, Faculty of Agriculture, Ain-Shams University, Cairo, Egypt. (NC)

Sardeshpande, J.S., Goyal, S.K. (1982) Effect of insecticides on growth and nitrogen fixation by blue-green algae. Pages 588–605 in *Biological nitrogen fixation*. Proceedings of a National Symposium, Indian Agricultural Research Institute, New Delhi. (NS)

*Notes:* The effect of Carbofuran, endosulfan, phorate, and gamma BHC (1, 5, 20, and 50 ppm) was tested on growth (optical density), and N<sub>2</sub> fixation (N accumulated) in cultures of *Anabaena iyengarii*, *Hapalosiphon intricatus*, *Calothrix membranacea*, and *Calothrix bharadwajae*. It was concluded that at the recommended doses of field application (0.3 to 1.5 ppm) these insecticides had no deleterious effect on the algae. Carbofuran and phorate at 1 ppm appreciably increased the growth and N<sub>2</sub> fixation of *A. iyengarii* and *C. membranacea*. Inhibitory effects was observed at concentrations higher than 5 ppm.

Satapathy, K.B., Singh, P.K. (1987) Effect of the pesticides carbofuran and phorate on the growth of water fern *Azolla pinnata* R. BR. varieties and their pests. *Beitrag trop. Landwirtschaft. Veterinarmed.* 25(4): 411–417.

*Summary:* Water fern *Azolla pinnata* R. BR. is able to fix N, from the air and is therefore of increasing importance for the cultivation of rice. That is why this plant receives special attention in Asian countries as green manure. In a field trial the effect was tested of the insecticides carbofuran and phorate on the most important pests and the growth of *Azolla pinnata*. Four varieties were used from India, Vietnam, Thailand, and Bangladesh. Both insecticides were applied in concentrations of 0.075 and 0.15 kg ai/ha for the control of the larvae of *Nymphula responsalis* Walk. and *Cryptoblabes gnidiella* Mill. At the higher concentration carbofuran was found to significantly affect the development of the pests and the growth fern. Increased applications of phorate did not yield any improved effect. A comparison of the various provenances of *Azolla pinnata* showed that the variety from Bangladesh had a relatively higher tolerance to the pests. For the other varieties, control with carbofuran (0.15 kg ai/ha) is advised.

Schauberger, C.W., Wildman, R.B. (1977) Accumulation of aldrin and dieldrin by blue-green algae and related effects on photosynthetic pigments. *Bull. Environ. Contam. Toxic.* 17: 534–541. (NS)

*Notes:* Studied of the bioconcentration of aldrin and dieldrin at 1 g/li by *Anabaena cylindrica*, *Anacystis nidulans*, and *Nostoc muscorum*. After seven

days, concentration of pesticides in algae ranged from traces to 1.3 µg/g for aldrin and from 0.2 to 1.8 µg/g for dieldrin, indicating a marked bioconcentration of both pesticides. Concentration up to 10 ppm aldrin or dieldrin in the culture medium had no marked effect on the growth of the three algae but higher concentrations were inhibitory.

Schluter, M. (1965) The effect of several fungicides and herbicides on freshwater algae under laboratory conditions. *Z. Fisch.* 314: 303. (NC)

*Notes:* Little effect of 20 to 60 ppm 2,4-D on cultures of three green algae, two BGA, and one diatom over an eight-week test period.

Shabana, E.F. (1985) Use of algal batch assays to assess the toxicity of atrazine to some selected blue-green algae: 1. Influence of atrazine on the growth, pigmentation and carbohydrate contents of *Aulosira fertilissima*, *Anabaena oryzae*, *Nostoc muscorum* and *Tolypothrix tenuis*. *Egypt. J. Physiol.* 12(1): 67–76.

*Summary:* The data presented in this investigation revealed that the gain in the dry weights of all test algae was suppressed under all herbicide treatments, particularly at higher concentrations. However, at the lowest dose of the herbicide, the growth inhibition was statistically significant in *Anabaena* and insignificant in the other algae. Chlorophyll a content in *Anabaena* was slightly and insignificantly increased at lower concentration; a phenomenon that was furthered by increasing the herbicide dose. On the other hand, the pigment biosynthesis was suppressed, under all treatments, in *Tolypothrix* and *Aulosira*, being more effective and statistically significant in the latter. The pigment accumulation in *Nostoc* was slightly and insignificantly promoted by all herbicide doses except at the highest concentration where a slight drop was noticed. The herbicide was most efficient at lower doses, in stimulating glucose absorption by either *Nostoc* and *Anabaena* up to 0.1 ppm thereabove, remarkable drop was maintained. It induced significant retardation in the sugar uptake by *Tolypothrix* and *Aulosira*. Such trend was furthered by increasing the herbicide concentration. Under all treatments of atrazine the total carbohydrate accumulation in all test algae was suppressed being more effective at the lowest concentration in *Tolypothrix* and *Aulosira* and of less significant effect in *Anabaena* and *Nostoc*. It may be concluded that the toxic effects of atrazine are partially due to its inhibitory effects on the synthesis of carbohydrates.

Shabana, E.F. (1987a) Use of batch assays to assess the toxicity of atrazine to some selected cyanobacteria: Influence of atrazine on the growth, pigmentation, and carbohydrate contents of *Aulosira fertilissima*, *Anabaena oryzae*, *Nostoc muscorum* and *Tolypothrix tenuis*. *J. Basic Microbiol.* 27(2): 113–119. (NC)

Shabana, E.F. (1987b) Use of batch assays to assess the toxicity of atrazine to some selected cyanobacteria. II. Effect of atrazine on heterocyst frequency, nitrogen and phosphorus metabolism of four heterocystous cyanobacteria. *J. Basic Microbiol.* 27(4): 215–223.

*Summary:* Atrazine added in different doses to the culture media, augmented with glucose, of *Aulosira fertilissima*, *Tolypothrix tenuis*, *Anabaena oryzae* and *Nostoc muscorum* enhanced heterocyst frequency and efficiency of nitrogen fixation. Variations in the amounts of fixed nitrogen between the four test organisms may be attributed to differences in the levels of the high energy substance ATP, and also to various effects on the permeability barrier of cells. Although atrazine is a metabolic inhibitor, it enhanced particularly the nitrogen and phosphorus metabolism, leading to more amino-N and protein-N accumulation, yielding active synthesis of organic phosphorus, total soluble and insoluble phosphorus contents.

Shalan, S.N., Alaa El-Din, M.N., El-Sayed, M., Khadr, M.S., Shahr, M. (1982) Effect of herbicides on the rice yield inoculated with blue-green algae. Paper presented at the first OAU/STRC Inter-African Conference on Bio-fertilizers, Cairo (Egypt), March 22–26. (NC)

Shalan, S.N., Alaa El-Din, M.N., Hassan, M.E., Khadr, M.S. Shahr, M. (1984) Effect of herbicides on the rice yield inoculated with blue-green algae. Second Conference of the Agricultural Research Centre, Giza, Egypt, April 9–11. (NC)

Shankar, K.M., Varghese, T.J. (1981) Evaluation of potassium permanganate for control of *Microcystis* bloom. *Mysore J. Agric. Sci.* 15: 150–153.

*Summary:* Observations made on the phytotoxic effect of  $\text{KMnO}_4$  on the bloom forming blue-green alga *Microcystis* sp., are reported.  $\text{KMnO}_4$  was found to be effective in controlling *Microcystis* at a dosage of 8 ppm. The death of the alga was confirmed by microscopic observations. Bioassay experiments revealed that the above concentration was not lethal to carp fingerlings. However, zooplankton like rotifers and cladocerans could not withstand the dosage of 8 ppm of  $\text{KMnO}_4$ , whereas copepods were not affected. Observations on the addition of oxygen in  $\text{KMnO}_4$  treated water were also made, and DO values between  $\text{KMnO}_4$  and  $\text{CuSO}_4$  treated waters were compared.

Sharma, V.K. (1984) Pesticide interaction with cyanobacterial nitrogen fixation and paddy yield in India. *Environ. Conserv.* 11(3): 265–267. (NS)

*Notes:* A short review with eight references.

Sharma, V.K., Gaur, Y.S. (1980) Growth, nitrogen and carbohydrate contents in nitrogen-fixing algal strains resistant to pesticides. Pages 47–50 in *Proceeding of the National Working of Algal Systems*. Indian Society of Biotechnology, IIT/ New Delhi 110016, India.

*Summary:* The effects of five combination of pesticides on paddy-field algae (*Nostoc* sp. and *Aulosira fertilissima*) under  $N_2$ -fixing conditions in the laboratory were studied. An increased growth was obtained in only one strain of each alga, but the percentage of total N decreased in all strains. However, relatively less decrease in percentage of total N was observed in strains of both algae resistant to PMA, MEMC, Lindane combination. Similarly, little decrease in percentage of carbohydrates was observed in resistant strains of *Nostoc* sp. and *Aulosira fertilissima*. Only fast growing pesticide resistant strains excreted more N in the culture filtrates in comparison to normal strains.

*Notes:* *In vitro* experiments on the effect of five combinations of PMA, MEMC, Lindane, and Phosvel on strains of *Nostoc* and *Aulosira* adapted to pesticides by repetitive subculturing in medium with pesticide. N content decreased in all strains but decrease was minimum in adapted strains. Fast growing pesticide resistant strains excreted more N than parent strains.

Sharma, V.K., Gaur, Y.S. (1981) Nitrogen fixation by pesticide-adapted strains of paddy field cyanophytes. *Intl. J. Ecol. Env. Sci.* 7: 117–122.

*Summary:* Tolerance limits of the  $N_2$ -fixing cyanophytes to certain paddy-field pesticides has been studied. The reduction in total nitrogen content of the pesticide-adapted strains has been ascribed to the inhibition of some stage(s) during the process of dinitrogen fixation or protein formatin or perhaps both.

Sharma, V.K., Gaur, Y.S. (1982) Interaction of paddy-crop pesticides with nitrogen-fixing cyanophytes. *Pesticides* 82: 5–6.

*Summary:* While it has been found that application of pesticides retard both growth and fixation of atmospheric nitrogen by paddy-field algae, their sensitivity to different pesticides vary considerably.

Shilo, M. (1965) Study on the isolation and control of blue-green algae from fish ponds. *Bamidjeh* 17: 83. (NC)

Shivaprakasha, M.K., Shivappa Shetty, K. (1986) Effect of three common agricultural chemicals on growth and nitrogen fixation by blue-green algae. *J. Soil. Biol. Ecol.* 6: 16–23. (NC)

Shivaram, S., Shivappa Shetty, K. (1988) Studies on the effect of pesticides on the growth and nitrogen fixation by blue-green algae. *Mysore J. Agric. Sci.* 22: 222–225.

*Summary:* Six blue-green algal isolates viz. *Anabaena variabilis*, *Calothrix* sp., *Cylindrospermum musicola*, *Hapalosiphon welwitschii*, *Nostoc* sp. and *Scytonema hofmani* were tested for their growth and N<sub>2</sub> fixing ability under different concentrations of three pesticides viz. Rogor, Dithane M-45, and 2,4-D sodium salt in pure culture. The growth and N<sub>2</sub> fixation by all the six isolates were favoured at lower concentrations of the pesticides whereas higher concentrations gave an adverse effect.

Shatina, E.A. (1957a) Die Einwirkung des Herbizids 2,4-D auf die Bodenalggen. *Tr. Kirovsk Sel'choz Inst.* 12: 24. (NC)

Sidorenko, O.D., Klyuchareva, N.N., Nitse, L.K. (1986) Nitrogen-fixing activity of soil samples in ricefields after application of herbicides and straw. *Izv. Timiryasev S-KH. Akad.* 5: 188–191. (NS)

*Notes:* In Russian with no English summary.

Singh, A.L., Singh, P.K., Singh, P.L. (1988) Effects of different herbicides on the *Azolla* and blue-green algal biofertilization of rice. *J. Agric. Sci.* 111 (3): 451–458.

*Summary:* Pre-emergence herbicides applied at field recommended doses, three days after transplanting (DAT) rice plants, inhibited growth and N<sub>2</sub>-fixation of *Azolla pinnata* (Bangkok) and BGA (blue-green algae) inoculated 10 DAT. This inhibition was up to 15 DAT in *Azolla* and up to 20 DAT in BGA. Butachlor and oxadiazon resulted in higher toxicity to *Azolla* and BGA than benthioncarb and pendimethalin. The application of 0.5 kg/ha active ingredient of 2,4-DNa did not inhibit growth of *Azolla* but inhibited BGA growth. However, 2,4-DEE [2,4-D ethyl ester], a post-emergence herbicide, applied 30 DAT showed inhibitory effects on the growth and N<sub>2</sub>-fixation of both *Azolla* and BGA. Inoculation of 2.0 t/ha of fresh *Azolla* 10 DAT produced maximum biomass within 20–25 days of herbicide treatments, depending upon the season. The inoculation of 10 kg/ha of a dry mixture of BGA 10 DAT could produce the maximum biomass 60 and 80 DAT in control and herbicide treated plots, respectively. The biomass and nitrogen produced by *Azolla* recorded at maximum mat formation were similar in both herbicide treated and untreated plots, but in BGA these were higher in controls than those of herbicide treated plots. The use of *Azolla* and BGA biofertilizers along with herbicides increased the grain and straw yields,

and panicle number and nitrogen uptake, by rice over no *Azolla* or BGA treatments. The *Azolla* and BGA treatments even without weeding increased rice yield up to that of herbicide and biofertilizer treatments.

Singh, D.P., Singh, P.K. (1988) Effects of phosphorus and carbofuran on the growth and nitrogen fixation of *Azolla pinnata* and the yield of rice. *Expl. Agric.* 24: 183–189.

*Summary:* The effects of phosphorus fertilizer and the insecticide carbofuran on the growth and  $N_2$ -fixation of *Azolla pinnata* and on the growth, grain yield and nitrogen uptake of intercropped rice were examined in a wet and a dry season. Treatment with phosphorus or carbofuran increased the biomass of *Azolla* and the amount of  $N_2$  fixed (nitrogen yield) in both seasons, but the response was much better in the dry season. *Azolla* inoculation at 1.0 t/ha resulted in a greater biomass and nitrogen yield than inoculation at 0.5 t/ha. In the dry season, a combination of phosphorus and carbofuran enhanced the growth and  $N_2$ -fixation of *Azolla* more than either treatment alone. Carbofuran treatment slowed the rate of *Azolla* decomposition, particularly in the dry season. The plant height, leaf area index and dry matter production of rice at flowering time were increased in the plots treated with phosphorus or carbofuran in the wet season and these treatments increased rice grain yield and nitrogen uptake in both the wet and dry seasons.

Singh, D.T., Nirmala, K., Modi, D.R., Katiyar, S., Singh, N.H. (1987) Genetic transfer of herbicide resistance gene(s) from *Gloeocapsa* sp. to *Nostoc muscorum*. *Mol. Gen. Genet.* 208(3): 436–438.

*Summary:* An aerobic diazotrophic *Gloeocapsa* strain contained genes conferring resistance to the growth toxic effects of ricefield herbicides Machete and Basalin. The results of genetic crosses and of DNA-mediated genetic transformation experiments both suggested the absence of a heterospecific barrier for the transfer of herbicide resistance genes from a *Gloeocapsa* strain to *Nostoc muscorum* and their stable expression and maintenance in the latter. These findings will have considerable implications in cyanobacterial biofertilizer technology.

Singh, H.N., Singh, H.R., Vaishampayan, Y. (1979) Toxic and mutagenic action of the herbicide alachlor (Lasso) on various strains of the  $N_2$ -fixing blue-green alga *Nostoc muscorum* and characterization of the herbicide-induced mutants resistant to methylamine and L-methionine-DL O sulfoximine. *Environ. Expt. Bot.* 19(1): 5–12.

*Summary:* Alachlor (lasso), like butachlor (machete) shows mutagenic properties when tested in *Nostoc muscorum* systems. The mutagenicity of the two herbicides seems considerably higher than that of MNNG (N-methyl-N'-nitro-N-nitroso guanidine). A dose of alachlor considerably higher than that of butachlor is needed to obtain a comparable level of growth inhibition and mutagenesis, thus suggesting that butachlor is the more efficient mutagen. Methylamine-resistant (MA-R) and L-methionine-DL-sulfoximine-resistant (MSO-R) mutants have been obtained spontaneously or following mutagenic treatment with either herbicide. MA-R strains appear to metabolize methylamine as a nitrogen source. MSO-R strains do not form heterocysts in  $\text{ON}^{-3}$  or  $\text{NH}^{+4}$  medium containing or lacking MSO; the parent *N. muscorum* does not form heterocysts in  $\text{NO}^{-3}$  or  $\text{NH}^{+4}$  medium lacking MSO but does form them in either nitrogen medium containing MSO.

Singh, H.N., Vaishampayan, A. (1978) Biological effects of rice-field herbicide Machete on various strains of the nitrogen-fixing blue-green alga *Nostoc muscorum*. *Environ. Exper. Bot.* 18(2):87-94.

*Summary:* The pre-emergence ricefield herbicide Machete (2-chloro-2', 6'-diethyl-N (butoxy methyl) acetanilide), is apparently toxic and lytic to parental,  $\text{het}^+ \text{nif}^-_{11}$ , and Em-R  $\text{het}^- \text{nif}^-_2$  strains of *Nostoc muscorum*. The intensity of the biological effects induced by the herbicide increases with the growth-promoting efficiency of various inorganic nitrogen sources. The herbicide has no effect on heterocyst differentiation, and induced biological perturbations are not reversed by glucose. Machete appears to be strong mutagen as 5-6 percent of the  $\text{het}^+ \text{nif}^-_{11}$  and Em-R  $\text{het}^- \text{nif}^-_2$  are prototrophic revertants.

Singh, L.J., Tiwari, D.N. (1988) Some important parameters in the evaluation of herbicide toxicity in diazotrophic cyanobacteria. *J. Appl. Bacteriol.* 64(5): 365-370.

*Summary:* The effect of different inocula sizes on the toxicity of the herbicides machete, basalin and propalin was tested. The inocula sizes gave differential response pattern towards a particular herbicide dose and, as such, the employment of a specific dose inoculum response is suggested. Furthermore, *Gloeocapsa* sp. showed remarkable herbicide resistance potential while *Nostoc muscorum* was quite susceptible to all the herbicides.

Singh, L.J., Tiwari, D.N., Singh, H.N. (1986) Evidence for genetic control of herbicide resistance in a ricefield isolate of *Gloeocapsa* sp. capable of aerobic diazotrophy under photoautotrophic conditions. *J. Gen. Appl. Microbiol.* 32(2): 81-88.



*Summary:* The ricefield isolate of *Gloeocapsa* sp. grew aerobically at the expense of  $N_2$  as a nitrogen source and showed DCMU-sensitive aerobic nitrogenase activity under photoautotrophic conditions. The two pre-emergence ricefield herbicides Machete and Basalin strongly inhibited growth, photosynthesis, respiration, and nitrogenase activity in *Nostoc muscorum*, in a concentration hardly inhibitory to these processes in *Gloeocapsa* sp. Ethidium bromide treatment of *Gloeocapsa* sp. resistant to growth inhibition by Machete and Basalin resulted in nonreversible loss of both herbicide resistant phenotypes (Macr and Basr) without affecting aerobic diazotrophy. The nonreversible Macs Bass strain resulting from Ethidium bromide treatment of Macr Basr *Gloeocapsa* strain stopped growth,  $N_2$ -fixation, and photosynthetic  $O_2$  evolution when inoculated in growth medium containing 10 or 20 g/ml of Machete, Basalin, or both. These findings suggest that the ricefield isolate of *Gloeocapsa* sp. is a naturally occurring Machete and Basalin resistant strain dependant on photosynthesis for aerobic diazotrophy and that the genes for the two herbicide-resistant phenotypes are possibly plasmid-borne. The present findings will have a significant bearing on the future of cyanobacterial biotechnology in agriculture.

Singh, P.K. (1973) Effects of pesticides on blue-green algae. *Arch. Mikrobiol.* 89: 317–320.

*Summary:* Effect of pesticides, i.e., Benzene Hexachloride, Lindane, Diazinon and Endrin that are often used in India was observed on  $N_2$ -fixing blue-green algae *Cylindrospermum* sp., *Aulosira fertilissima* and aerobically non- $N_2$ -fixing blue-green alga *Plectonema boryanum* strain 594. These algae were sensitive for BHC in comparison to other pesticides. *A. fertilissima* and *P. boryanum* were more resistant than *Cylindrospermum* sp.

Singh, P.K. (1974) Algicidal effect of 2,4-dichlorophenoxy acetic acid on blue-green alga *Cylindrospermum* sp. *Arch. Microbiol.* 97: 69–72.

*Summary:* The effect of the herbicide 2,4-Dichlorophenoxy acetic acid generally used in agriculture was studied on the  $N_2$  fixing blue-green alga *Cylindrospermum* sp. The alga could tolerate up to 150 g per ml in liquid culture and 100 g per ml on agar plates without any inhibitory effect on growth and survival. The maximum tolerance was up to 800 g per ml and higher concentrations were lethal.

Singh, R.K., Singh, B., Singh, H.N. (1983) Inhibition of photosystem II of the nitrogen-fixing blue-green alga *Nostoc linckia* by the ricefield herbicide benthicarb. (Eng) *Z. Allg. Mikrobiol.* 23(7): 435–441.

*Summary:* Effects of ricefield herbicide benthocarb (S-(4-chlorobenzyl)-N,N-diethyl thiocarbamate) was studied on the N<sub>2</sub>-fixing blue-green alga *N. linckia*. The herbicide caused inhibition of growth and heterocyst formation, an increase in intensity of photoacoustic signals and a four-fold reduction in oxygen evolution but did not affect dark O<sub>2</sub>-uptake. The inhibition of growth and heterocyst formation was relieved by 500 g/ml glucose. A Het<sup>-</sup>Nif<sup>-</sup> mutant of *N. muscorum* failed to show an increase in reversion frequency after treatment with 10 g/ml benthocarb for one hour.

Singh, R.P., Singh, R.K., Tiwari, D.N. (1986) Effect of herbicides on the composition of cyanobacteria in transplanted rice. *Plant Prot. Q* 1(3): 101–102.

*Summary:* The effect of butachlor (1.5 kg ai/ha), thiobencarb (1.5 kg ai/ha) and 2,4-D (1.5 kg ai/ha) on the presence of N<sub>2</sub>-fixing photosynthetic procaryotic cyanobacteria was studied in rice bays during the summer monsoon at Varanasi, India. Herbicides at the recommended rate had little effect on the percentage of *Phormidium*, *Microcystic* and *Microcoleus* sp. present in the algal biomass. All herbicides increased the proportion of the blue-green algae such as *Nostoc*, while only propanil reduced the proportion of *Anabaena* in the algae population. In general, the recommended rates of herbicide did not result in major changes in the composition of the algal population.

*Notes:* Field experiment showing that, in general, the recommended doses of herbicides did not result in major changes in the composition of the algal population. However all herbicides increased the proportion of *Nostoc* sp.

Singh, V.P., Singh, B.D., Dhar, B., Singh, R.M., Srivastava, J.S., Singh, R.B. (1978) Effect of herbicide, alachlor on growth and nitrogen fixation in cyanobacteria and rhizobia. *Indian J. Exp. Biol.* 16(12): 1325–1327.

*Summary:* Rhizobium strain SU391 was more resistant to alachlor than other strains. Two nitrogen fixing, filamentous species of cyanobacteria were more sensitive than a unicellular non-fixing species. Rhizobia tolerated four to five times higher concentrations than the cyanobacteria. Heterocysts in *Anabaena doliolum* were spaced more widely when grown in 5–40 µg/dml alachlor. Nitrogen fixation in *A. doliolum* and *Nostoc muscorum* was adversely affected only at relatively higher concentrations (above 20 µg/ml).

Singh, V.P., Singh, R.B., Singh, B.D., Singh, R.M., Dhar, B., Srivastava, J.S. (1978) Toxicity of butachlor to nitrogen-fixing microorganisms. *Beitr. Bid. Pflanz.* 54(2): 227–238.

**Summary:** Toxicity of the herbicide butachlor [2-chloro-2,6-diethyl-N (butoxymethyl) acetanilide] was determined *in vitro* on seven strains of *Rhizobium* sp. and three species of blue-green algae. *R. leguminosarum* strains (SU 391, 1045 and P 5) showed a more resistant growth pattern than other strains, 32H1, CB756, M7 (cowpea *Rhizobium*) and CB1809 (*R. japonicum*). The unicellular non-N-fixing blue-green alga, *Aphanothece stagnina*, was more resistant than the two filamentous N-fixing species. The *Rhizobium* tolerated 10- to 50-fold higher concentrations of butachlor (100 µg/ml) than the blue-green algae (2 or 10 µg/ml). Low concentrations of butachlor (0.5–2.0 µg/ml) significantly increased heterocyst spacing in *Anabaena doliolum*. The N-fixing ability of *A. doliolum* and *Nostoc muscorum* in 1 µg/ml butachlor was comparable to the control, but at the higher concentrations (2–8 µg/ml) it was adversely affected, especially in the case of *A. doliolum*.

Sinha, P.K., Pal, S., Trial, S.B. (1986) An effective molluscicide for grazer snails of blue green algae. *Pesticides* 20(2): 44–45.

**Summary:** The snails of irrigation water were found grazing severely blue green algae of paddy fields. Available insecticides viz carbofuran, phorate, carbaryl, endosulfan, diazinon, chlorpyrifos, and thiodicarb were tried in the laboratory to control their damage. Thrice replicated five concentrations i.e. 100, 50, 10, 5 and 1 ppm of above insecticides were tried and two recordings of mortality at four and 24 hours were made after the treatment. Thiodicarb proved cent percent effective at 5 ppm and even at 1 ppm after four and 24 hours respectively. It also proved safer to BGA and local fishes of paddy fields at 1 ppm.

Smith, R.J., Jr., Flinchum, W.T., Seaman, D.E. (1977) *Weed control in U.S. rice production*. Agriculture Handbook No. 497, USDA, Washington DC. 78 pp.

**Notes:** Includes tables summarizing the control of common ricefield weeds by cultural practices and pesticides.

Smith, R.J., Jr., Viste, K.L., Shaw, W.C. (1959) Progress in weed control in rice production in the United States. *Int. Rice Comm. Newsl.* 8(3): 1–6.

**Summary:** The significant results of five years of investigations on the control of weeds in the rice-producing areas of Arkansas and California have been discussed. No attempt has been made to present all the technical results of these investigations. A method of controlling weed grasses in the south-eastern rice-producing area involving the use of CIPC in combination with several cultural management practices has been developed. The combination herbicide-cultural

practice was used effectively to control barnyard grass and other weed grasses on more than 5,000 acres of commercially grown rice in 1959. In the western rice-producing area, CIPC and EPTC, in combination with various cultural practices, have shown experimental promise for the control of barnyard grass and other weed grasses; but these herbicides are not presently suggested for commercial use. Intensive fundamental investigations have been conducted to develop basic information on the use of 2,4-D, MCPA, 2,4,5-T, and silvex for the most effective control of a wide range of broadleaved weeds and sedges with minimum risk of injury to rice. It is estimated that over 40 percent of the total rice crop in the United States is treated annually with phenoxy-type herbicides for the control of weeds. Basic and applied studies are being continued to improve current weed-control practices and to develop new herbicides and new improved chemical-cultural methods of controlling weeds in rice.

Srinivasan, S. (1981a) Control of daphnids in blue-green algae multiplication plots. (Eng) *Int. Rice Res. Newsl.* 6(3): 16. (NS)

Notes: Carbofuran, Carbaryl, BHC, Quinalphos, Mephosfolan, Phorate, and Diazinon applied at normal rate (0.6–1.3 kg ai/ha) significantly increased BGA growth in plots used for the production of soil-based inoculum.

Srinivasan, S. (1981b) Screening blue-green algae types tolerant of daphnids in paddy fields. (Eng) *Int. Rice Res. Newsl.* 6(2): 18–19. (NS)

Notes: Field experiment on BGA production in inoculum multiplication plots. Refers to grazer control by carbofuran and Ekalux.

Srinivasan, S., Ponnuswami, V. (1978) Influence of weedicides on blue-green algae. *Aduthurai Rep.* 2(11): 136. (NS)

Notes: Field experiment on BGA production in inoculum multiplication plots. Among nine formulations tested at the recommended dose, three significantly decreased inoculum production by an average 36 percent. When the dose was doubled, four formulations significantly reduced algal production.

Stratton, G.W. (1984) Effects of the herbicide atrazine and its degradation products, alone and in combination, on phototrophic microorganisms. *Arch. Environ. Contam. Toxicol.* 13(1): 35–42.

Summary: Toxic effects of the herbicide atrazine and four of its degradation products were determined for growth, photosynthesis and acetylene-reducing ability of two species of green algae [*Chlorella pyrenoidosa*, *Scenedesmus quadricauda*] and three species of cyanobacteria [*Anabaena inaequalis*, *A.*

*cylindrica*, *A. variabilis*]. Atrazine was significantly more toxic than its degradation products towards the test criteria, yielding EC<sub>50</sub> values ranging from 0.1–0.5 ppm (g/ml) for photosynthesis and 0.3–5.0 ppm for growth. De-ethylated atrazine was the next most toxic with EC<sub>50</sub> values of 0.7–4.8, and 1.0–8.5 ppm for photosynthesis and growth, respectively. With deisopropylated atrazine the EC<sub>50</sub> values for the same physiological functions ranged from 3.6–9.3 and 2.5 to > 10 ppm, respectively. Hydroxy- and diamino-atrazine were nontoxic towards most cultures. Acetylene reduction with cyanobacteria was insensitive to all test compounds, except for atrazine, which had an EC<sub>50</sub> of  $55 \pm 15$  ppm towards *A. inaequalis*. Combinations of atrazine and its monodealkylated products were tested with *A. inaequalis* and yielded synergistic, antagonistic and additive interaction responses, depending upon the actual test system employed.

Stratton, G.W., Burrell, R.E., Lynn Kurp, M., Corke, C.T. (1980) Interactions between the solvent acetone and the pyrethroid insecticide permethrin on activities of the blue-green alga *Anabaena*. *Bull. Environm. Contam. Toxicol.* 24: 562–569. (NS)

Stratton, G., Corke, C.T. (1981) Effect of acetone on the toxicity of atrazine towards photosynthesis in *Anabaena*. *J. Environ. Sci. Health Part B Pestic. Food Contam. Agric. Wastes* 16(1): 21–34.

*Summary:* The effect of acetone on the toxicity of atrazine towards photosynthesis in the blue-green algae *Anabaena inaequalis*, *A. variabilis* and *A. cylindrica* was investigated. The order of sensitivity to atrazine was *A. inaequalis* > *A. variabilis* > *A. cylindrica*. Acetone and atrazine interacted additively, antagonistically, and synergistically, depending upon the concentrations of acetone and atrazine used. The EC<sub>50</sub> of atrazine towards photosynthesis was dependent upon the type of solvent-pesticide interaction.

Stratton, G.W., Corke, C.T. (1982) Toxicity of insecticide permethrin and some degradation products towards algae and cyanobacteria. *Environ. Pollut. Ser. A Ecol. Biol.* 29(1): 71–80. (NC)

Subba-Rao, R.V., Alexander, M. (1980) Effect of DDT metabolites on soil respiration and on an aquatic alga. *Bull. Environ. Contam. Toxicol.* 25: 215–220. (NS)

*Notes:* DDT and DDT metabolites (DDE, DDD, DDA, PCPA, BHE, DCBHE, DDM, DBH, DPB) at 1 and 10 ppm had: no marked effect on the chlorophyll content and biomass of *Chlorella vulgaris* measured as the average values and concentration in eight and 13 days cultures; no marked effect on soil respiration

measured for two to three days after pesticide application with classical respirometric techniques on 0.5 g of soil.

Subramanian, G. (1982) The effect of pesticides on nitrogen fixation and ammonia excretion by *Anabaena*. Pages 567–587 in *Proceeding of the National Symposium on Biological Nitrogen Fixation*, New Delhi. (NS)

*Notes:* Laboratory study of the effect of BHC, Carbaryl, Ekalux, and Dithane on the growth, ARA, and ammonium excretion by four *Anabaena* sp.

Subramanian, G., Shanmugasundaram, S. (1986) Influence of the herbicide 2–4-D on nitrogen fixation and ammonia excretion by the cyanobacterium *Anabaena*. *Proc. Ind. Nat. Sci. Acad. Part B Biol. Sci.* 52(2): 308–312.

*Summary:* 2,4-D (2,4-Dichlorophenoxyacetic acid) at concentrations of 1–100 ppm did not have any adverse effect on six strains of *Anabaena*. The growth was stimulated in some strains. While in some strains, nitrogenase activity was considerably stimulated, in others, the activity decreased with increasing concentrations. The excretion of ammonia under the influence of 2,4-D varied with the strains and showed no correlation to nitrogenase activity.

Snyder, C.E., Sheridan, R.P. (1974) Toxicity of the pesticide Zectran on photosynthesis, respiration and growth in four algae. *J. Phycol.* 10: 137. (NC)

Takamura, K. Yasuno, M. (1986) Effects of pesticide applications on chironomids, ostracods and other benthic organisms in ricefields. *Res. Rep. Natl. Inst. Environ. Stud. Japan* 99: 81–90.

*Summary:* Benthic organisms were surveyed in ricefields treated with pesticides differently during late May–August, 1983; no pesticide, herbicide only, and herbicide + insecticide + fungicide. Total count of benthic bacteria decreased from the other of 1,010 cell/ml to the order of 109 cells/ml after the simultaneous application of insecticide and herbicide. Chironomids and ostracods appeared in large numbers. They increased markedly in the pesticide-treated fields. Larval populations of odonates and dytiscids which prey on chironomid larvae and ostracods, were depressed with pesticides. This result allowed the marked increase in the populations of chironomids of their numbers each other in some degree. Benthic algae decreased with applications of herbicide and did not increase markedly in the pesticide-treated fields. The latter cases could also be ascribed to heavy grazing by chironomids and ostracods.

*Notes:* Field survey showing a decrease from  $10^{10}$ /ml to  $10^9$ /ml of the total benthic bacteria in herbicide + insecticide treated fields as well as the development

of large populations of chironomids and ostracods. Simultaneously, the number of natural predators of chironomids and ostracods decreased. Benthic algae decreased in herbicide treated plots and did not increase in insecticide treated plots probably because of grazing by ostracods.

Takamura, K., Yasuno, M. (1986) Effects of pesticide application on chironomid larvae and ostracods in ricefields. *Appl. Ent. Zool.* 21(3): 370–376.

*Summary:* Benthic macroinvertebrates were surveyed in ricefields in which three pesticide applications were adopted; no pesticide, herbicide only, and herbicide + insecticide + fungicide. Abundant taxa were chironomid and ostracod. The populations of these animals fluctuated widely in the pesticide-treated ricefields. Larval populations of odonates and dytiscids which prey on chironomid larvae and ostracods, were depressed according as various pesticides were applied. The low density of predators presumably allowed the large increase in the populations of chironomids and ostracods. However, competition between chironomids and ostracods, as well as the direct toxic effect of pesticides, may have suppressed the increase of their numbers in some degree. Benthic algae decreased with most applications of herbicide. The algae showed a slight increase probably due to heavy grazing by chironomids and ostracods and to herbicide toxicity in the pesticide-treated fields.

Tandon, R.S., Lal, R., Narayana, Rao, VVS (1988) Interaction of endosulfan and malathion with blue-green algae *Anabaena* and *Aulosira fertilissima*. *Environ. Pollut.* 52(1): 1–10.

*Summary:* The growth of *Anabaena* and *Aulosira fertilissima* was adversely affected by endosulfan even at 1 µg/ml. The inhibition was significantly above 50 percent at 20 µg/ml throughout the incubation. *Anabaena* survived up to 500 µg/ml of malathion, but was completely bleached in the presence of 50 µg/ml of endosulfan. *Aulosira* was more sensitive to malathion than *Anabaena* and recovered to control levels only at 10 µg/ml. The morphology and heterocyst frequency were not altered in *Anabaena*. *Aulosira* cultures were dull brown in colour at 20 µg/ml of endosulfan with the filaments clumping, instead of the usual mat formation. Both malathion and endosulfan considerably lowered <sup>14</sup>C uptake and nitrogenase activities in *Aulosira*. Nitrogen fixation was unaffected in *Anabaena* as the amounts of ethylene produced were equal to, or above, control levels. The impact of these insecticides on photosynthesis in *Anabaena* was only slight.

Tarar, J.L., Shewale, T.H. (1984) Studies on the effects of some fungicides on soil algae of paddy fields. *Phykos* 23(1–2): 191–201. (NC)

Theivendirarajah, K., Jeyaseelan, K. (1981) Effect of herbicide, isopropyl ester of 2,4-dichlorophenoxyacetic acid (2,4-Dipe), on blue-green algae. *Ceylon J. Sci.* 14(1/2): 10–14.

*Summary:* The effect of the hormonal herbicide Isopropyl ester of 2P-Dichloro phenoxyacetic acid (2,4-DIFE) on the growth of two  $N_2$ -fixing blue-green algae *Nostoc carneum* and *Anabaena* sp. and the non- $N_2$ -fixing blue-green alga *Anacystis nidulans* was studied. The rate of growth and the final cell number of these algae were not affected by this weedicide even at a concentration that is approximately 15 times more than the concentration used in paddy soils.

Tirol, A.C., Santiago, S.T., Iwao Watanabe, I. (1981) Effect of the insecticide, carbofuran, on microbial activities in flooded soil. *J. Pestic. Sci. (Nihon Noyakugaku Kaishi)* 6(1): 83–90.

*Summary:* The effects of carbofuran in some soil microbial activities (N mineralization, nitrification, N-fixation by blue-green algae, and urea hydrolysis) were investigated in the laboratory and the greenhouse. The addition of 10  $\mu\text{g ai}$  [active ingredient] carbofuran/g dried soil had no inhibitory effect on the mineralization of native soil N. Nitrifying activity was enhanced in flooded soil treated with 10, 20, 50 and 100 ppm ai carbofuran. Nitrifying activity increased with increasing carbofuran concentration. The growth of blue-green algae was promoted by the addition of 6 kg ai carbofuran/ha to the floodwater. Subsequently, a marked increase in the acetylene reduction activity of carbofuran-treated floodwater was obtained. Turbidity and an abundance of green algae distinguished the untreated floodwater from the carbofuran-treated one. The positive effect of carbofuran on phototrophic  $N_2$ -fixation appeared after its decomposition. The addition of up to 15 ppm ai ( $\mu\text{g/ml}$  floodwater) carbofuran had no effect on the acetylene-reduction activity of *Gloeotrichia* sp., but 20 ppm ai caused a significant lowering of that activity. The rate of urea hydrolysis apparently was faster in dry land than in flooded soil. The addition of 50 ppm ai carbofuran did not affect the rate of urea hydrolysis.

Tiwari, D.N., Pandey, A.K. (1981) 2,4-D-resistant mutant strains of *Anacystis nidulans* and filament formation. *Indian J. Exp. Biol.* 19(10): 988–990.

*Summary:* Spontaneous mutants of the unicellular blue-green alga, *A. nidulans*, resistant to 2,4-D were isolated; the mutant frequencies ranged  $2 - 8 \times 10^6$ . The concentration of the herbicide (2 mg/ml), lethal to the parent clone, permitted the growth of presumptive herbicide-resistant mutants in the form of filaments. These mutants did not show filamentous growth in herbicide-free medium. Several successive generations in basal herbicide-free medium and retransfer of



measured for two to three days after pesticide application with classical respirometric techniques on 0.5 g of soil.

Subramanian, G. (1982) The effect of pesticides on nitrogen fixation and ammonia excretion by *Anabaena*. Pages 567–587 in *Proceeding of the National Symposium on Biological Nitrogen Fixation*, New Delhi. (NS)

*Notes:* Laboratory study of the effect of BHC, Carbaryl, Ekalux, and Dithane on the growth, ARA, and ammonium excretion by four *Anabaena* sp.

Subramanian, G., Shanmugasundaram, S. (1986) Influence of the herbicide 2–4-D on nitrogen fixation and ammonia excretion by the cyanobacterium *Anabaena*. *Proc. Ind. Nat. Sci. Acad. Part B Biol. Sci.* 52(2): 308312.

*Summary:* 2,4-D (2,4-Dichlorophenoxyacetic acid) at concentrations of 1–100 ppm did not have any adverse effect on six strains of *Anabaena*. The growth was stimulated in some strains. While in some strains, nitrogenase activity was considerably stimulated, in others, the activity decreased with increasing concentrations. The excretion of ammonia under the influence of 2,4-D varied with the strains and showed no correlation to nitrogenase activity.

Synder, C.E., Sheridan, R.P. (1974) Toxicity of the pesticide Zectran on photosynthesis, respiration and growth in four algae. *J. Phycol.* 10: 137. (NC)

Takamura, K. Yasuno, M. (1986) Effects of pesticide applications on chironomids, ostracods and other benthic organisms in ricefields. *Res. Rep. Natl. Inst. Environ. Stud. Japan* 99: 81–90.

*Summary:* Benthic organisms were surveyed in ricefields treated with pesticides differently during late May–August, 1983; no pesticide, herbicide only, and herbicide + insecticide + fungicide. Total count of benthic bacteria decreased from the other of 1,010 cell/ml to the order of 109 cells/ml after the simultaneous application of insecticide and herbicide. Chironomids and ostracods appeared in large numbers. They increased markedly in the pesticide-treated fields. Larval populations of odonates and dytiscids which prey on chironomid larvae and ostracods, were depressed with pesticides. This result allowed the marked increase in the populations of chironomids of their numbers each other in some degree. Benthic algae decreased with applications of herbicide and did not increase markedly in the pesticide-treated fields. The latter cases could also be ascribed to heavy grazing by chironomids and ostracods.

*Notes:* Field survey showing a decrease from  $10^{10}$ /ml to  $10^9$ /ml of the total benthic bacteria in herbicide + insecticide treated fields as well as the development

*Summary:* The effect of the herbicide simazine on the algal and cyanobacterial population of a cultivated soil was studied. The results obtained showed that heterocystous, nonheterocystous cyanobacteria and microalgae were differently affected by the repeated use of simazine (4 kg/ha), the first being more severely affected. Moreover the herbicide produced a strong reduction in the species diversity. This reduction was very evident in the case of heterocystous cyanobacteria.

Torres, A.M.R., O'Flaherty, L.M. (1976) Influence of pesticides on *Chlorella*, *Chlorococcum*, *Stigeoclonium* (Chlorophyceae) and *Oscillatoria* (Cyanophyceae). *Phycologia* 15: 25. (NC)

Tubea, B., Hawxby, K., Mehta, R. (1981) The effects of nutrient, pH and herbicide levels on algal growth. *Hydrobiologia* 79(3): 221–228.

*Summary:* Growth inhibition of algae [*Chlorella pyrenoidosa* and *Lyngbya birgei*] increased as herbicide concentrations increased, particularly with prometryn and fluometuron. Picloram had no effect on algal growth and dinoseb inhibited only *L. birgei*. There were no differences in growth rate of algae treated with different levels of K or P. High levels of Ca or Mg increased growth rate of the algae tested. High levels of N or pH increased growth rates except when combined with prometryn or fluometuron.

Tucker, C.S., Lloyd, S.W. (1987) Evaluation of potassium ricinoleate as a selective blue-green algicide in channel catfish ponds. *Aquaculture* 65(2): 141–148.

*Summary:* The effectiveness of potassium ricinoleate as a selective blue-green algicide was investigated in experimental channel catfish, *Ictalurus punctatus*, culture ponds. Five ponds were treated with 0.8 mg/l potassium ricinoleate three times per week from May through October and five ponds served as controls. Treatment did not affect concentrations of chlorophyll-a, total and un-ionized ammonia-nitrogen, or dissolved oxygen; nor did it affect average hours of supplemental aeration or net fish production. The mean nitrite-nitrogen concentration in control ponds was higher ( $P < 0.05$ ) than that in treated ponds, but concentrations of nitrite never reached levels considered detrimental to the health of the fish. Treatment did not reduce the incidence or percentage of blue-green algae in phytoplankton communities and did not prevent severe episodes of off-flavor in fish from treated ponds.

Vaishampayan, A. (1984a) Biological effects of a herbicide on a nitrogen-fixing cyanobacteria (blue-green alga): an attempt for introducing herbicide-resistance. *New Phytol.* 96(1): 7–11.

*Summary:* The herbicide monuron (3-(4-chlorophenyl)-1,1-dimethylurea) inhibits growth and heterocyst formation in the  $N_2$ -fixing cyanobacterium *Nostoc muscorum*. These inhibitory effects are glucose-reversible in both  $N_2$  (nitrogen-free) and  $NO_3^-$  media. A spontaneous mutant of this cyanobacterium, resistant to a dose of monuron normally applied to the ricefields of North India, has been isolated and preliminarily characterized as having no requirement for an organic carbon source for its normal physiology under monuron-treated conditions. The behavior of the mutant has been tentatively explained as resulting from a permeation mutation preventing monuron entry into *N. muscorum*.

Vaishampayan, A. (1984b) Powerful mutagenicity of a bipyridylum herbicide in a nitrogen-fixing blue-green alga *Nostoc muscorum*. *Mutat. Res.* 138(1): 39–46.

*Summary:* The herbicide, paraquat (1,1'-dimethyl-4,4'-bipyridylum ion), was toxic and lytic to *N. muscorum* in  $N_2$  (at the expense of elemental N, i.e., unsupplemented with any combined N source) and  $NO_3^-$  media, without any apparent inhibitory or stimulatory effect on its  $N_2$  fixing apparatus, i.e., heterocyst formation. At a dose of paraquat resulting in 20, 50 and 75 percent survival, induction of reverse mutations (from *het<sup>-</sup> nif<sup>-</sup>* auxotrophy to *het<sup>-</sup> nif<sup>+</sup>* prototrophy), forward mutations (for streptomycin [St]-resistance) and auxotrophic mutations (C-auxotrophy through methylamine [MA]-resistance) were observed with frequencies comparable to those obtained through induction with the well known mutagen MNNG (N-methyl-N'-nitro-N-nitrosoguanidine).

Vaishampayan, A. (1984c) Studies on diuron uptake in a blue-green alga *Nostoc muscorum*. *J. Exp. Bot.* 35(155): 897–904.

*Summary:* A mutant of *Nostoc muscorum* that is resistant to 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron) has been selected. This mutant may lack the step in photosynthesis that is affected by diuron (DCMU), but it can also use DCMU as a source of carbon and nitrogen. Another mutant of this organism resistant to L-methionine-DL-sulphoximine (MSO), that was isolated previously, also shows some cross resistance to DCMU.

Vaishampayan, A. (1985a) Biological effects on the ricefield herbicide monuron on a  $N_2$ -fixing cyanobacterium *Nostoc muscorum*. *Microbios Lett.* 28: 105–111.

*Summary:* The herbicide monuron (3-(4-chlorophenyl)-1,1-dimethylurea) has been found to be an inhibitor of growth and heterocyst differentiation in the  $N_2$ -fixing cyanobacterium *Nostoc muscorum*. The inhibitory effects of monuron have been shown to be at the level of photosynthetic assimilation of inorganic

measured for two to three days after pesticide application with classical respirometric techniques on 0.5 g of soil.

Subramanian, G. (1982) The effect of pesticides on nitrogen fixation and ammonia excretion by *Anabaena*. Pages 567–587 in *Proceeding of the National Symposium on Biological Nitrogen Fixation*, New Delhi. (NS)

*Notes:* Laboratory study of the effect of BHC, Carbaryl, Ekalux, and Dithane on the growth, ARA, and ammonium excretion by four *Anabaena* sp.

Subramanian, G., Shanmugasundaram, S. (1986) Influence of the herbicide 2–4-D on nitrogen fixation and ammonia excretion by the cyanobacterium *Anabaena*. *Proc. Ind. Nat. Sci. Acad. Part B Biol. Sci.* 52(2): 308–312.

*Summary:* 2,4-D (2,4-Dichlorophenoxyacetic acid) at concentrations of 1–100 ppm did not have any adverse effect on six strains of *Anabaena*. The growth was stimulated in some strains. While in some strains, nitrogenase activity was considerably stimulated, in others, the activity decreased with increasing concentrations. The excretion of ammonia under the influence of 2,4-D varied with the strains and showed no correlation to nitrogenase activity.

Snyder, C.E., Sheridan, R.P. (1974) Toxicity of the pesticide Zectran on photosynthesis, respiration and growth in four algae. *J. Phycol.* 10: 137. (NC)

Takamura, K. Yasuno, M. (1986) Effects of pesticide applications on chironomids, ostracods and other benthic organisms in ricefields. *Res. Rep. Natl. Inst. Environ. Stud. Japan* 99: 81–90.

*Summary:* Benthic organisms were surveyed in ricefields treated with pesticides differently during late May–August, 1983; no pesticide, herbicide only, and herbicide + insecticide + fungicide. Total count of benthic bacteria decreased from the other of 1,010 cell/ml to the order of 10<sup>9</sup> cells/ml after the simultaneous application of insecticide and herbicide. Chironomids and ostracods appeared in large numbers. They increased markedly in the pesticide-treated fields. Larval populations of odonates and dytiscids which prey on chironomid larvae and ostracods, were depressed with pesticides. This result allowed the marked increase in the populations of chironomids of their numbers each other in some degree. Benthic algae decreased with applications of herbicide and did not increase markedly in the pesticide-treated fields. The latter cases could also be ascribed to heavy grazing by chironomids and ostracods.

*Notes:* Field survey showing a decrease from 10<sup>10</sup>/ml to 10<sup>9</sup>/ml of the total benthic bacteria in herbicide + insecticide treated fields as well as the development

resulting in ~ 20 and 50 percent survival of *N. muscorum*, respectively, various mutations were obtained. These include reverse mutation (reversion of  $\text{het}^+ \text{nif}^-$  and  $\text{het}^- \text{nif}^-$  auxotrophic markers to  $\text{het}^+ \text{nif}^+$  prototrophy); forward mutation (for resistance to 1 ppm streptomycin and 2.5 ppm erythromycin); auxotrophic mutation (for the achievement of carbon-auxotrophy through methylamine-resistance). The toxic and mutagenic effects of these herbicides were compared with those of the well known mutagen N-methyl-N'-nitro-N-nitrosoguanidine and found to be stronger than the latter in each case.

Vaishampayan, A., Prasad, A.B. (1982) Blitox-resistant mutants of the  $\text{N}_2$ -fixing blue-green algae *Nostoc linkia* and *Nostoc muscorum*. *Environ. Expt. Bot.* 22(4): 427. (NC)

Vaishampayan, A., Singh, H.R., Singh, H.N. (1978) Biological effects of ricefield herbicide "Stam f-34" on various strains of the nitrogen-fixing blue-green alga *Nostoc muscorum*. *Biochem. Physiol. Pflanz.* 173(5): 410–419.

*Summary:* The post-emergence ricefield herbicide Stam f-34 is inhibitory to growth and heterocyst differentiation in the heterocystous  $\text{N}_2$ -fixing parent and heterocystous non- $\text{N}_2$ -fixing ( $\text{het} \text{ hif}_{11}^-$ ) mutant strains of the blue-green alga *Nostoc muscorum* G. Similar effect is exerted by 3-(3,4-dichlorophenyl)-1,1-dimethylurea (DCMU) on two strains. Glucose and acetate both are quite effective in reversing the inhibitory action of both Stam f-34 and DCMU. The L-isomers of amino acids glutamine, citrulline, arginine, methionine, valine and leucine individually support the mutant growth in nitrogen-free medium, while L-alanine fails to do so and L-glutamate is quite toxic to the growth of the parent strain. Stam f-34 or DCMU-inhibition of growth and heterocyst differentiation in both the parent and mutant strains is easily overcome by citrulline, methionine and valine. Neither herbicide is found to be mutagenic for inducing reversion to prototrophy in  $\text{het}^+ \text{nif}_{11}^-$  strain. These findings seem to suggest that Stam f-34 mode of action is like that of DCMU and that readily assimilable amino acids can serve as a good carbon and nitrogen source in *Nostoc muscorum*.

Vance, B.D., Drummond, W. (1969) Biological concentration of pesticides by algae. *J. Am. Water Works Assoc.* 61: 360. (NC)

Venkataraman, G.S., Rajyalakshmi. (1971) Tolerance of blue-green algae to pesticides. *Curr. Sci.* 40: 143–144. (NS)

Venkataraman, G.S., Rajyalakshmi, B. (1972) Relative tolerance of blue-green algae to pesticides. *Indian J. Agric. Sci.* 42: 119–121.

*Summary:* Twenty-seven strains of N<sub>2</sub>-fixing blue-green algae belonging to four genera were tested for their *in vitro* tolerance to different concentrations of two fungicides and six herbicides. The algae showed a high but varied tolerance. In general, these algae could grow at high concentrations of the chemicals.

Watanabe, I., Subudhi, B.P.R., Aziz, T. (1981) Effect of neem cake on the population and nitrogen fixing activity of blue-green algae in flooded soil. *Curr. Sci.* 50(21): 937–939.

*Summary:* Neem cake stimulated the growth of blue-green algae in flooded soil possibly by depressing the activity of grazers, and enhanced photodependent N<sub>2</sub>-fixation. Those effects were first observed in the greenhouse, and a similar trend was found in the field.

Wegener, K.E., Aldag, R., Meyer, B. (1985) Soil algae: Effects of herbicides on growth and C<sub>2</sub>H<sub>2</sub> reduction (nitrogenase) activity. *Soil Biol. Biochem.* 17(5): 641–644.

*Summary:* The influence of the soil-applied herbicides chlortoluron, terbutryne, metabenzthiazuron, chloridazon, and dinosebacetate as well as the fungicide carbendazime on the growth and nitrogenase activity of soil algae was tested. The degree of algal cover on the soil surface was correlated with the measured C<sub>2</sub>H<sub>2</sub>-reduction (nitrogenase) activity. All the herbicides tested at recommended rates of application caused a total suppression of algal growth and C<sub>2</sub>H<sub>4</sub> generation for several weeks. The fungicide had no detectable effect on algal populations or C<sub>2</sub>H<sub>2</sub> reduction.

Wright, S.J.L. (1978) Interactions of pesticides with micro-algae. Pages 535–602 in *Pesticide microbiology*, Hill, I.R., Wright, S.J.L. (eds). Academic Press, London. (NS)

*Notes:* A review with 225 references.

Wright, S.J.L., Maule, A. (1982) Transformation of the herbicides propanil and chlorpropham by microalgae. *Pestic. Sci.* 13(3): 253–256.

*Summary:* Two species of green algae and four of blue-green algae hydrolyzed the acylanilide herbicide propanil to the aniline derivative, 3,4-dichloroaniline. Of the cultures tested, only the blue-green alga *Anacystis nidulans* was shown to be capable of converting the phenylcarbamate herbicides propham and chlorpropham to the corresponding anilines. The green alga *Ulothrix fimbriata* was apparently unable to hydrolyze propanil or chlorpropham.

Wright, S.J.L., Stainhorpe, A.F., Downs, J.D. (1977) Interactions of the herbicide propanil and a metabolite, 3,4 dichloroaniline, with blue-green algae. *Acta Phytopathol. Acad. Sci. Hung.* 12(1/2): 51–60.

*Summary:* At concentrations below those used for weed control, propanil significantly inhibited the photoautotrophic growth of several blue-green algae, including  $N_2$ -fixing species common in soil and ricefields. Sensitivity to propanil was affected by growth conditions. *Gloeocapsa alpicola* (unicellular) was the most propanil sensitive of the algae tested. Low concentrations ( $< 0.03$  ppm) of propanil slightly stimulated some algae, intermediate concentrations ( $< 0.2$  ppm) reduced growth in all species and caused cellular abnormalities in some, while concentrations above 5 ppm stopped photosynthesis and prevented algal growth. The metabolite 3,4-dichloroaniline (DCA), formed in algal cultures, was far less inhibitory than propanil to algal growth. Propanil addition to growing cultures of *A. cylindrica* caused a phase of lysis which was followed by recovery on continued incubation.

Wurtsbaugh, W.A., Apperson, C.S. (1978) Effects of mosquito control insecticides on nitrogen fixation and growth of blue-green algae in natural plankton associations. *Bull. Environm. Contam. Toxicol.* 19: 641–647. (NS)

Yamagishi, A., Hashizume, A. (1974) Ecology of green algae in paddy fields and their control with chemicals. *Zasso Kenkyu* 18: 39. (NC)

Yee, D., Weinberger, P., Johnson, D.A., Dechacin, C. (1985) *In vitro* effects of the S-triazine herbicide, prometryne, on the growth of terrestrial and aquatic microflora. *Arch. Environ. Contam. Toxicol.* 14(1): 25–32.

*Summary:* A green alga (*Chlamydomonas segnis*), a cyanobacterium (*Anabaena* sp.) and two  $N_2$ -fixing bacteria (*Klebsiella pneumoniae*, strain M5A1 and *Rhizobium japonicum*, strain 61A76) were separately exposed to concentrations of the S-triazine herbicide, prometryne, from 0.25–12.0 g/ml. Growth parameters observed included cell number (*C. segnis*), heterocyst frequency (*Anabaena* sp.) and generation time (*K. pneumoniae* and *R. japonicum*). A decrease in the population of *C. segnis* and heterocyst frequency of *Anabaena* sp. were noted after exposure to the herbicide. Full recovery was obtained in cleared cultures of *C. segnis* plated on pesticide-free nutrient agar. Similar recovery was not obtained in washed *Anabaena* sp. cells. *K. pneumoniae* was relatively insensitive to the herbicide; the generation time of *R. japonicum*, when exposed to 6.8 g/ml prometryne, was increased three-fold compared to untreated cultures (26.25 h vs. 9.5 h).

Zargar, M.Y., Dar, G.H. (1990) Effect of Benthocarb and Butachlor on growth and nitrogen fixation by cyanobacteria. *Bull. Environ. Contam. Toxicol.* 45: 232–234. (NS)

*Notes:* In vitro experiments on a mixed culture of *Anabaena*, *Nostoc*, and *Oscillatoria* showed that 35 ppm Benthocarb and 90 ppm Butachlor had no significant effect on algal dry weight produced in eight days.

Zeitseva, I.I. (1979) The influence of soil herbicides on the nitrogen fixing activity of blue green algae. *Mikrobiologie* 32: 60. (NC)

Zullei, N., Benecke, G. (1978) Application of new bioassay to screen the toxicity of polychlorinated biphenyls on blue-green algae. *Bull. Environm. Contam. Toxicol.* 20: 786–792.

*Summary:* A new bioassay was applied testing the toxicity of several PCB's and tetrachlorodibenzo-p-dioxin against blue-green algae. TCDD, mono-, di-, and trichlorobiphenyls inhibited the motility of *Phormidium* sp., while higher chlorinated biphenyls had no effect.

Zurek, L. (1982) The influence of the herbicides lenacil and pyrazon on soil algae. *Ekol. Pol.* 29(3): 327–342.

*Summary:* The influence of two herbicides, lenacil (cyclohexylo-5–6-trimethylenouracyl) and pyrazon (1-phenylo-4- = amino-5-chloro-6-ketopyridasine), on soil algae was investigated under field and laboratory conditions. In the laboratory experiment, lenacil showed a higher and longer lasting toxicity than pyrazon. Its lethal doses in aqueous culture amounted to 0.0148 mg. dm<sup>-3</sup> of medium for the blue-green alga *Anabaena variabilis*, and to 0.023 mg. dm<sup>-3</sup> for the green alga *Chlorhormidium flaccidum*. The lethal doses of pyrazon amounted to 0.055 mg. dm<sup>-3</sup> and 1.658 mg. dm<sup>-3</sup>, respectively. Both herbicides impoverished the species composition and decreased the density of algal assemblages in plots.

## **Part 2. Pesticides Used in Experiments with Algae Occurring in Ricefields and Summary of Their Effects (*in vitro* and *in situ* Experiments)**

Common names and commercial names are listed by alphabetic order.

Commercial names are referred to the common name.

The nature of the pesticide is indicated in the first parenthesis.



The chemical name (according to the International Union of Pure and Applied Chemistry, IUPAC) is indicated in the second parenthesis.

Information on recommended dose for application is indicated in kg/ha when available from the *Pesticide Manual* (Worthing and Walker, eds., 1983) and in lbs/acre when obtained from "Agriculturals chemicals" (Thomson, 1979); a question mark (?) indicates that recommended dose is neither available from these two reference books nor from the original paper.

Concentrations in ppm, kg/ha, and lbs/acre refer to active ingredient if not otherwise indicated. References listed without comments are dealing with the effects of the listed pesticide but do not include quantitative data that could be tabulated in terms of inhibition at a pesticide level expressed in ppm.

2,3-Dichloronaphthoquinone: see Dichlone

2,4-D, Weedone (herbicide) ([2,4-dichlorophenoxy] acetic acid): 2,4-D, its salts and esters are systemic herbicides at 0.28–2.3 kg/ha.

Arvik et al. (1971) *In vitro*, 400 ppm had no effect on *Chlorella vulgaris*, *Cylindrospermum licheniforme*, and *Chlorococcum* sp.

Bahal (1969) *In vitro*, simulative effect on heterocyst development in *Anabaena ambigua*.

Bednarz (1981) *In vitro*, Chlorococcal green algae were more sensitive than filamentous green and blue-green algae. Tolerant species decreased the toxicity of the herbicide to sensitive algae.

Das and Singh (1977b) *In vitro*, 100 ppm was not inhibitory for *Anabaenopsis raciborskii*.

Das and Singh (1978a)

Hawxby et al. (1977) *In vitro*, concentrations up to 10  $\mu$ mol had no effect on *Lyngbia*, *Anabaena*, *Chlorococcum* and *Chlorella*.

Hamdi et al. (1970) *In vitro*, 0.045 ppm, 25 percent inhibition; 0.45 ppm, 45 percent inhibition; 4.5 ppm 30 percent inhibition on cultures of *Tolypothrix tenuis*.

Holst et al. (1982) *In vitro*, after 10 days, 0.1 and 1 ppm did not inhibit *Azolla* sp. growth on N<sub>2</sub>, 10 ppm caused a total inhibition.

Hotter et al. (1979) *In vitro*, the concentration causing a 50 percent reduction of photoautotrophic growth was 50 ppm for *Aphanocapsa* 6714, 700 ppm for *Aphanocapsa* 6308, 100 ppm for *Anabaena variabilis*, and 250 ppm for *Nostoc* sp.

Inger (1970) *In vitro*, affect the growth of *Nostoc muscorum*, *Nostoc punctiforme* and *Cylindrospermum* at concentrations recommended for field

- application, but was stimulatory at low concentrations  $-10^4$  - $10^{-5}$  M
- M. Khalil et al. (1980) *In vitro*, 500 ppm was not algicidal for *Nostoc* sp., *Tolypothrix tenuis*, and *Mastigocladus laminosus*.
- Mishra and Pandey (1989) *In vitro*, 100 ppm 2,4-D stimulated the growth and nitrogen fixation by *Nostoc linckia*, *Nostoc calcicola*, *Nostoc* sp., and *Anabaena doliolum*.
- Padhy (1985)
- Pandey and Tiwari (1986) *In vitro*, 100 ppm stimulated the growth of *Nostoc linckia*; 1500 ppm was lethal.
- Pillay and Tchan (1972) *In vitro*, 1 and 5 ppm had no effect on the growth of *Chlorella* sp., *Scenedesmus* sp., *Chlorococcum* sp., *Chlamydomonas* sp., *Euglena* sp., *Botrydiopsis* sp., *Nostoc* sp., *Anabaena* sp.
- Schluter (1965) *In vitro*, little effect of 20 to 60 ppm 2,4D on cultures of three green algae, two BGA, and one diatom over a eight-week test period.
- Shivaram and Shetty (1988) *In vitro*, 15 ppm had no negative effect at 30 days on the dry weight of *Anabaena variabilis*, *Calothrix* sp., and *Cylindrospermum musicola*. 5 ppm had no or little effect on *Hapalosiphon welwitschii*, *Nostoc* sp. and *Scytonema hofmani*.
- P.K. Singh (1974) *In vitro*, at 16 days, 300 ppm was not inhibitory to *Cylindrospermum* sp.
- R.P. Singh et al. (1986) *In situ*, 1.5 kg/ha had no significant effect on the composition of algal populations studied by direct counts.
- Smith et al. (1977) *In situ*, control of BGA was not achieved with 2–3ppm.
- Srinivasan and Ponnuswami (1978) single dose of the formulation (Weedone 18 percent WP 2 kg/ha) decreased the production of BGA in inoculum multiplication plots by about 40 percent.
- Subramanian and Shanmugasundaram (1986) *In vitro*, 100 ppm had no detrimental effect on BNF of three *Anabaena* strains, inhibited it by less than 50 percent in two strains and by more than 50 percent in one strain. 10 ppm had no effect on 5/6 strains and inhibited one by 50 percent. 1 ppm inhibited 1 strain by 40 percent.
- Theivendirajah and Jeyaseelan (1981) *In vitro*, 64 ppm had no effect on *Nostoc carneum*, *Anabaena* sp., and *Anacystis nidulans*. 200 ppm was lethal.
- Tiwari et al. (1981) *In vitro* 2,4-D increased the growth of *Nostoc linckia* at doses up to 100 g/ml.
- Tiwari et al. (1982) *In vitro*, 100 ppm was stimulatory to *Anabaena cylindrica* growth.
- Tiwari and Pandey (1981) *In vitro*, the growth of *Anacystis nidulans* was not affected by 500 ppm.
- Venkataraman and Rajylakswami (1971) *In vitro*, 17 strains of BGA could grow at > 100 ppm, one at 50 ppm, and one at 5 ppm.

2,4,5-T (herbicide) ([2,4,5-trichlorophenoxy] acetic acid) Generally used in non crop areas. Used as post-emergence herbicide alone or with 2,4-D. Used at 1–12 lbs/acre (1.1–13.5 kg/ha) by aircraft or ground sprayers.

Padhy (1985)

Smith et al. (1977) *In situ*, control of BGA and green algae was not achieved with 2–3 ppm.

2,4,5-TP, Silvex (Herbicide) (2-(2,4,5-trichlorophenoxy) propionic acid) used at 1–4 lbs/acre (1.1–4.4 kg/ha)

Smith et al. (1977) *In situ*, control of BGA and green algae was not achieved with 2–3 ppm.

3-chloroaniline (herbicide):

Maule and Wright (1983) *In vitro*, 24 ppm had little effect on pigments of *Chlamydomonas reihardil* and *Anacystis nidulans*; more than 300 ppm was needed to significantly reduce O<sub>2</sub> evolution.

Agallol: see 2-methoxyethylmercury chloride

Alachlor, Lasso (herbicide, algicide) (2-chloro-2', 6'-diethyl-N-methoxymethyl acetanilide): Selective pre- or early post-emergence herbicide used at 1.7–4.5 kg/ha.

Hawxby et al. (1977) *In vitro*, concentrations up to 10 mol had no effect on *Chlorococcum*, *Lyngbia*, and *Anabaena* while 10 mol reduced *Chlorella* growth by 60 percent.

Holst et al. (1982) *In vitro*, after 10 days, 0.1 and 1 ppm partially inhibited *Azolla* sp. growth on N<sub>2</sub>, 10 ppm caused a total inhibition.

Kumar and Singh (1981) *In vitro* at 10 days of growth, 1–20 ppm caused partial growth inhibition < 20 percent in *Anabaena doliolum*; 50 ppm was lethal. 1–5 ppm caused partial growth inhibition < 25 percent in *Nostoc* sp.; 10 ppm was lethal.

Mukerji and Laha (1979) *In situ*, 2.5 kg/ha was inefficient to control *Chara* and *Hydrilla*.

H.N. Singh et al. (1979) 200 ppm was lethal to *Nostoc muscorum*.

Aldicarb (insecticide) (2-methyl-2-(methylthio) propionaldehyde 0-methyl-carbamo yloxime): Soil-applied systemic pesticide used at 0.6–11.2 kg/ha.

Mallison and Cannon (1984) *In vitro*, at 31 days, 10 ppm inhibited the growth of *Plectonema borianum* by 30 percent.

Aldrex: see Aldrin

Aldrin, Aldrex (insecticide) ([1R,4S,4aS,5S,8R,8RaR]-1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4:5,8-dimethanonaphthalene): Insecticide highly effective against a range of soil-dwelling pests, its principal use is in agriculture at 0.5–5.0 kg/ha.

Batterton et al. (1971), Bongale (1985) *In vitro*, 10 ppm inhibit the growth of *Hapalosiphon* sp. by 6–23 percent, and *Nostoc microscopicum* by 50 percent.

Padhy (1985)

Schauberger and Wildman (1977) *In vitro*, 10 ppm had no effect on *Anabaena cylindrica*, *Anacystic nidulans* and *Nostoc muscorum*; 50 percent inhibition was at about 50 ppm, 1,000 ppm was lethal.

Vance and Drummond (1969) *In vitro*, lethal dose was > 15 ppm for *Anabaena cylindrica*, < 5 ppm for *Microcystis aeruginosa*, > 20 ppm for *Senedsmus quadricauta*, and > 15 for *Oedogonium* sp.

Ametryne (herbicide) (2-ethylamino-4-isopropylamino-6-methylthio-1,3,5-triazine): used at 0.8–8 lbs/acre (1–9 kg/ha).

Mallison and Cannon (1984) *In vitro* at 14 days, 10 ppm completely inhibited the growth of *Plectonema borianum*.

Algaedyn (algicide) (?):

Padhy (1985)

Amitrole (herbicide) (1H-1,2,4-triazol-3-ylamine): Used in non crop areas, used at 1–20 lbs/acre (1.1–22.4 kg/ha).

DaSilva et al. (1974)

DaSilva et al. (1975) *In vitro*, 20 ppm stimulated BNF by nine strains of BGA; 20 ppm 3–5-D, a derivative, caused a temporary inhibition of BNF followed by stimulation in five of the nine strains.

Padhy (1985)

Atrazine (herbicide) (IUPAC 6-chloro-N-ethyl-N'-isopropyl-1,3,5-triazinediyl-2,4-diamine): used at 0.5–5 lbs/acre (0.6–5.6 kg/ha) (11–67 kg/ha for total control).

Allen et al. (1983)

Holst et al. (1982) *In vitro*, after 10 days, 0.1 ppm had no effect on *Azolla* sp. growth on N<sub>2</sub>, 1 ppm caused a partial inhibition, 10 ppm caused a total

inhibition. Hotter et al. (1979) [The concentration causing a 50 percent reduction of photoautotrophic growth *in vitro* was 0.52 ppm for *Aphanocapsa* 6714, 0.04 ppm for *Aphanocapsa* 6308, 0.1 ppm for *Anabaena variabilis*, and 0.26 ppm for *Nostoc* sp.

Mallison and Cannon (1984) *In vitro* at 31 days, 10 ppm inhibited the growth of *Plectonema borianum* by 35 percent.

Maule and Wright (1984) *In vitro* experiment with seven green algae and six BGA, EC50 values ranged from 0.06 to 5.4 ppm.

Padhy (1985)

Pillay and Tchan (1972)

Rower and Fluckiger (1979)

Shabana (1987)

Stratton (1984) *In vitro*, EC50 values for *Chlorella pyrenoidosa*, *Scenedesmus quadricauda*, *Anabaena inaequalis*, *A. cylindrica*, and *A. variabilis* ranged from 0.1 to 0.5 ppm for photosynthesis and from 0.3 to 5.0 ppm for growth.

Stratton and Corke (1981) Photosynthesis inhibition was 0 at 0.01 ppm, 48 percent at 0.05 ppm, and 90 percent at 0.25 ppm with *A. inaequalis*. It was 8 percent at 0.05 ppm, 33 percent at 0.25 ppm, and 65 percent at 0.5 ppm with *A. cylindrica*. It was 3 percent at 0.05 ppm, 60 percent at 0.10 ppm and 89 percent at 0.5 ppm with *A. variabilis*.

Barban (herbicide) (4-chlorobut-2-ynyl 3-chlorocarbamate): Selective post emergence herbicide applied at 4–6 oz/acre (0.4–0.6 kg/ha).

Padhy (1985)

Basalin: see Fluchloralin

Bavistin: see Carbendazim

Benomyl (fungicide) (methyl-1-(butyl-carbamoyl)-2-benzimidazolyl carbamate): Systemic fungicide used at 0.15–0.5 kg ai/ha.

Cameron and Julian (1984)

Holst et al. (1982) *In vitro*, after 10 days, 10 ppm had no effect on *Azolla* sp. growth on N<sub>2</sub>.

Ben(z)thiocarb, Saturn (herbicide) (S-(p-chlorobenzyl) diethylthiocarbamate): used at 3–6 kg ai/ha to the surface of the water 3–5 d before or 5–10 d after sowing or 3–7 d after transplanting.

Chen Pei Chung (1986) *In vitro*, 4 ppm had no effect on *Anabaena* CH<sub>2</sub> and CH<sub>3</sub>, 6–10 ppm had a partial inhibitory effects.

El-Haddad (1984) *In vitro*, 4 ppm had no effect on growth and BNF of *Nostoc muscorum* and *Anabaena oryzae*, 10 ppm caused a partial inhibition.

El-Sawy et al. (1984) *In pot*, 4 kg/ha had no effect on inoculated *Nostoc muscorum* and *Anabaena oryzae*.

Kumar and Singh (1981) *In vitro*, at 10 days, 1–50 ppm caused partial growth inhibition in *Anabaena doliolum*; 50 percent inhibition was at 3 ppm. 1–4 ppm caused partial growth inhibition in *Nostoc linckia*; 50 percent inhibition was at < 2 ppm.

R.K. Singh et al. (1983) *In vitro*, 1 ppm already caused partial inhibition of *Nostoc* sp. 50 percent inhibition was at 2 ppm.

R.P. Singh et al. (1986) *In situ*, 1.5 kg/ha had no significant effect on the composition of algal populations studied by direct counts.

Zargar and Dar (1990) *In vitro* experiments on a mixed culture of *Anabaena*, *Nostoc*, and *Oscillatoria* showed that 35 ppm Benthocarb had no significant effect on algal dry weight produced in 8 days.

#### Benzuride (algicide) (?):

Bisiach (1972a, b) *In vitro*, 8 ppm is inhibitory for *Spirogyra* and *Hydrodictyon*, and algicidal for *Oedogonium*.

BHC (insecticide) (Benzene hexachloride): used at 0.25–4.0 lbs/acre (0.30–4.4 kg/ha).

Das and Singh (1977a) *In vitro*, 60 ppm was inhibitory for *Anabaena raciborskii* and *A. aphanizomenoides*, 50 ppm was algistatic.

Das and Singh (1979) *In vitro* on *Microcystis flos aquae* 10 ppm did not affect the growth significantly, 10–80 ppm were algistatic and 100 ppm was algicidal.

Ishikawa and Matsuguchi (1966) *In beakers* experiments, at field level of application, had an inhibitory effect on diatoms but not on other components of the algal population.

Kaushik and Venkataraman (1983) *In vitro*, 1 and 10 ppm had no detrimental effect on ARA by *Hapalosiphon fontinalis*, *Hapalosiphon welwitschii*, *Westiellopsis prolifica*, *Westiellopsis* sp., and *Calothrix brauni*.

Padhy (1985).

Raghu and MacRae (1967) *In situ* 5 and 50 kg/ha promoted algal growth.

Sardeshpande and Goyal (1982) *In vitro*, 1 to 50 ppm partially inhibited N accumulation by *Anabaena iyengarii*, *Hapalosiphon intricatus*, *Calothrix*

*membranacea*, and *Calothrix bharadwaja* .. 50 percent inhibition was between 5 and 20 ppm.

Singh (1973) *In vitro*, at 18 days, 10 ppm inhibited *Cylindrospermum* by 18 percent but had no effect on *Aulosira fertilissima* at 50 ppm and on *Pectonema boryanum*, at 30 ppm.

Srinivasan (1981) *In situ*, 3.9 kg/ha significantly increased the production of BGA in inoculum production plots.

Subramanian (1982) *In vitro*, 10 ppm had no effect on four strains of *Anabaena*.

Blitane (fungicide, algicide) (37 percent metallic copper as Cu oxychloride + 22 percent Zineb):

Padhy (1985)

Blitox: see Copper oxychloride

Brassicol: see Quintozene

Brestan: see Fentin acetate

Bromacil (herbicide) (5-bromo-3-sec-butyl-6-methyluracil): Non-selective inhibitor of photosynthesis absorbed mainly through the roots and recommended for general weed control on uncropped land at 5–15 kg ai/ha. Used at 1.6–3.2 kg ai/ha for annual weed control.

Chen Pei Chung (1986) *In vitro*, no effect at 10 ppm on *Anabaena* CH<sub>2</sub> and CH<sub>3</sub>.

Pillay and Tchan (1972).

Butachlor, Machete (herbicide) (N-butoxymethyl-2-chloro-2',6'-diethylacetanilide): Pre-emergence herbicide used at 1.0–4.5 kg ai/ha.

Chen Pei Chung (1986) *In vitro*, no effect at 10 ppm on *Anabaena* CH<sub>2</sub> and CH<sub>3</sub>.

Kashyap and Pandey (1982) *In vitro* 0.5 to 10 ppm caused partial inhibition of *Anabaena dololium*, 2.5 ppm caused 50 percent reduction in growth, 20 ppm was algicidal.

Kerni et al. (1984)

Kumar and Singh (1981) *In vitro*, at 10 days of growth, 1–20ppm caused partial growth inhibition < 20 percent in *Anabaena doliolum*; 50 ppm was lethal. 1–5ppm caused partial growth inhibition in *Nostoc* sp.; 10 ppm was lethal.

Mishra and Pandey (1989) *In vitro*, 6–8ppm was lethal on *Nostoc linckia*, *Nostoc calcicoh*, *Nostoc* sp. and *Anabaena doliolum*.

Mukerji and Laha (1979) *In situ*, 2.5 kg/ha was algicidal to *Chara* and *Nitella* in seven days.

Padhy (1985)

Pandey and Kashyap (1986) *In vitro*, at 12 days or less, partial inhibition was observed at 0.5 ppm on the three tested strains; complete inhibition was observed at 2.5 ppm for *Anacystis nidulans*, 5 ppm for *Nostoc muscorum*, and 20 ppm for *Anabaena doliolum*.

Singh et al. (1987)

Singh and Vaishampayan (1978)

L.J. Singh et al. (1986) *In vitro*, 20 ppm had no effect on *Goeocapsa* while 10 ppm inhibited *Nostoc muscorum* by about 85 percent.

R.P. Singh et al. (1986) *In situ*, 1.5 kg/ha had no significant effect on the composition of algal populations studied by direct count.

Zargar and Dar (1990) *In vitro* experiments on a mixed culture of *Anabaena*, *Nostoc* and *Oscillatoria* showed that 90 ppm Butachlor had no significant effect on algal dry weight produced in eight days.

Camphechlor (insecticide) (a reaction mixture of chlorinated camphenes containing 67–69 percent chlorine):

Padhy (1985)

Captafol, Difolatan (fungicide) (N-(1,1,2,2-tetrachloroethylthio) cyclohex-4-ene-1,2-dicarboximide): Protectant non-systemic fungicide applied to foliage at c. 200 g ai/100 l.

Bisiach (1972) *In vitro*, 8 ppm is algicidal for *Spirogyra* and *Hydrodictyon*.

Gangawane and Saler (1979) *In vitro*, concentrations tolerated by various BGA were 300 ppm for *Westiellopsis* sp., 300 ppm for *Aulosira* sp., 100 ppm for *Calothrix* sp., 1,000 ppm for *Nostoc* sp., and 500 ppm for *Tolypothrix* sp.

Padhy (1985)

Captan, Hexacap: (fungicide) (N-(trichloromethylthio) cyclohex-4-ene-1,2-dicarboximide): used generally at 120 g ai/100 l.

Bharati and Angadi (1980)

Cameron and Julian (1984)

Gangawane and Saler (1979) *In vitro*, concentrations < 500 ppm had no effect on *Westiellopsis* sp., *Aulosira* sp., *Calothrix* sp., *Nostoc* sp. and *Tolypothrix* sp.



Gangawane et al. (1982), *In vitro*, 10 ppm was not inhibitory to *Nostoc* sp. and *Tolypothrix tenuis*.

Padhy (1985)

Carbaryl, NAC, Sevin (insecticide, molluscicide, grazer control) (1-naphthyl methyl carbamate): contact and stomach insecticide used at 0.25–2.0 kg ai/ha.

Adhikari (1989) Sevin had no significant effect on *Westiellopsis prolifica* growth measured *in vitro* 15 days after inoculation until 50 ppm, 50 percent inhibition was at 125 ppm, total inhibition was at 500 ppm.

Ahmad and Venkataraman (1973) no detrimental effect on *Aulosira fertilissima* when used at the recommended dose.

Ishizawa and Matsuguchi (1966) In beakers experiments had no significant effect at on algal populations when used at the recommended dose.

Megharaj et al. (1989a) *In vitro*, 20 ppm significantly increased the cell number of *S. bijugatus*. 5 ppm inhibited *Synechococcus elongatus*.

Megharaj et al. (1990) *In vitro*, 5 ppm had no effect on *Chlorella vulgaris*, 20 ppm caused 20 percent inhibition and 50 ppm 70 percent inhibition. 0.5 ppm had no effect on *Synechococcus elongatus*, 2 ppm caused 60 percent inhibition, and 5 ppm total inhibition. 10 ppm had no effect on *Nostoc linckia*, 20 ppm caused 20–50 percent inhibition.

Padhy (1985)

Sharma (1984)

Sinha et al. (1986) *In vitro*, 100 ppm is needed for use as molluscicide.

Srinivasan (1981) *In situ*, 2.4 kg/ha significantly increased the production of BGA in inoculum production plots.

Subramanian (1982) *In vitro*, 5 ppm had no effect on four strains of *Anabaena*, 50 ppm was lethal.

Carbendazim, Bavistin, MBC (fungicide) (methyl benzimidazol-2-ylcarbamate): banned in USA. Resistance has occurred. Used at ? kg/ha.

Gangawane (1980) *In vitro*, tolerant concentrations were 300 ppm for *Westiellopsis* sp., 100 ppm for *Aulosira* sp., 100 ppm for *Nostoc* sp., 50 ppm for *Tolypothrix* sp. while 1 ppm was algicidal for *Calothrix* sp.

Gangawane and Salers (1979) *In vitro*, concentrations lower than 1000 ppm had no effect on *Aulosira* sp. and *Tolypothrix* sp., concentrations lower than 500 ppm had no effect on *Calothrix* sp. and *Nostoc* sp., but 1 ppm was algicidal for *Westiellopsis* sp.

Gangawane et al. (1982) *In vitro*, 100 ppm was not inhibitory to *Nostoc* sp. and *Tolypothrix tenuis*.

Padhy (1985)

Wegener et al. (1985) In experiments with 23 g of non submerged soil carbendazime at 1, 2, and 3 times the recommended doses for field application had no major effect on algal growth and BNF.

Carbofuran, Furadan (insecticide, nematicide, molluscicide) (2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate): Systemic acaride, insecticide and nematicide, applied to foliage at 0.25–1.0 kg ai/ha and to seed furrow at 0.5–4.0 kg/ha.

Adhikari (1989) Carbofuran had no significant effect on *Westiellopsis prolifica* growth measured *in vitro* 15 d after inoculation until 3 ppm, 50 percent inhibition was at 7.5 ppm, total inhibition was at 30 ppm.

Ghost and Saha (1988) *In vitro*, 10 and 25 ppm significantly increased the chlorophyll content and dry weight of *Aulosira fertilissima*. Higher doses were found to be toxic. In soil cultures the tolerance was found to be much higher. Nitrogen fixation was encouraged up to 200 ppm during one and half month of incubation period.

Kar and Singh (1978) *In vitro*, 0.75 ppm enhanced growth and N<sub>2</sub>-fixation by *Nostoc muscorum*, 1.5–3 ppm was not or slightly inhibitory, 36 ppm was algicidal.

Kar and Singh (1979a, b, c) *In vitro*, depending on the level of nutrients in the medium, inhibition of the growth of *Nostoc mucorum* measured at 10 days was 23–55 percent with 7.5 ppm, 44–76 percent with 15 ppm, and 67–89 percent with 30 ppm.

Kaushik and Venkataraman (1983) *In vitro*, 10 ppm had no marked inhibitory effect on ARA by *Hapalosiphon fontinalis*, *Hapalosiphon welwitschii*, *Westiellopsis prolifica*, *Westiellopsis* sp. and *Calothrix brauni*.

Megharaj et al. (1988) In test tubes with soil, 0.5–2 kg/ha had no effect on total algal populations in flooded and non flooded soil at 10 and 20 days of incubation. 5 kg/ha had no effect in flooded soil but caused a transitory decrease in total algal population at 10 days in non flooded soil that disappeared at 20 days.

Megharaj et al. (1989a) *In vitro*, 20 ppm significantly increased the cell number of *Synechococcus bijugatus*. 5 ppm inhibited *Synechococcus elongatus*.

Padhy (1985)

Sardespande and Goyal (1982) *In vitro*, 1–20 ppm had no or little inhibitory effect on N accumulation by *Anabaena iyengarii*, *Hapalosiphon intricatus*, *Calothrix membranacea* and *Calothrix bharadwaja*. 50 ppm caused roughly 50 percent inhibition in the four strains.

Satapathy and Singh (1987) *In situ*, 0.15 kg ai/ha control insect pests of *Azolla* without detrimental effect on the fern.

Singh and Singh (1988) *In situ*, 90 g/ha favored *Azolla* growth.

Srinivasan (1981) *In situ*, 1.8 kg/ha significantly increased the production of BGA in inoculum production plots.

Tirol et al. (1981) *In situ*, 6 kg ai/ha promoted the growth of blue-green algae. Turbidity and an abundance of green algae distinguished the untreated floodwater from the carbofuran-treated one. The addition of up to 15 ppm ai (g/ml floodwater) carbofuran had no effect on the acetylene-reduction activity of *Gloeotrichia* sp., but 20 ppm ai caused a significant lowering of that activity.

Carboxin (fungicide) (5,6-dihydro-2-methyl-1,4-oxathi-ine-3-carboxanilide): Formulated alone or in combination with other fungicides. Used at 2–4 g/kg seed.

Cameron and Julian (1984) 2.3 ppm had no significant effect on *Nostoc* sp. growth. 23 ppm was lethal.

Padhy (1985)

Ceresan (fungicide) (N-(ethylmercury)-p-toluenesulphonanilide): Superseded compound banned in many countries.

Bharati and Angadi (1980)

Padhy (1985)

Sharma and Gaur (1980)

Venkataraman and Rajylakswami (1971) 15 strains of BGA could grow at 100 ppm, 3 at 10 ppm, and 4 were inhibited by 1 ppm.

Chloramben (herbicide) (3-amino-2,5-dichlorobenzoic acid): Selective pre-planting incorporated and pre-emergence herbicide applied at 2–4 lbs/acre (2.24.5 kg/ha).

Holst et al. (1982) *In vitro*, after 10 days, 10 ppm did not inhibit *Azolla* sp. growth on N<sub>2</sub>

Chloridazon (herbicide) (5-amino-4-chloro-2-phenylpyridazin-3(2H)-one): Effective against broad-leaved weeds and used at 1.6–3.3 kg ai/ha.

Wegener et al. (1985) In experiments with 23 g of non submerged soil, chloridazon at recommended dose for field application inhibited algal growth and BNF for about two months.

Chlorodimeform (insecticide) (N'-(4-chloro-o-tolyl)-N,N-dimethyl-formamidine): used at ? ? kg/ha.

Mallison and Cannon (1984)

Chloropicrin (insecticide, nematicide) (trichloronitromethane): used at ? kg/ha).

Ishizawa and Matsuguchi (1966) Beaker experiments possibly showed some partial inhibition of algal populations for 1-3 weeks.

Padhy (1985)

Chlortoluron (herbicide) (3-(3-chloro-p-tolyl)-1, 1-dimethylurea): Residual soil-acting herbicide and foliar spray, used at 1.5-3.0 kg ai/ha.

Amla and Kochhar (1982)

Wegener et al. (1985) In experiments with 23 g of non submerged soil chlortoluron, at recommended doses for field application (11 ppm), inhibited algal growth and BNF for about two months.

Chlorpropham (herbicide) (isopropyl 3-chlorocarbamate): selective carbamate used at 2-8 lbs/acre (2.2-9 kg/ha)

Maule and Wright (1983) *In vitro*, 10 ppm reduced ARA of *Anabaena cylindrica* by 20 percent and 15 ppm by 40 percent. 20 ppm had no significant effect on the photosynthetic oxygen production of *Anacystis nidulans*. Maule and Wright (1984) *In vitro* experiment with seven green algae and six BGA, EC50 ranged from 15 to 40 ppm for six BGA and 2 to 10 ppm for seven eukaryotic algae.

Chlorpyrifos (insecticide, molluscicide) (O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate): used at 0.1-5 lbs/acre (0.1-5.5 kg/ha).

Sinha et al. (1986) 50 ppm is needed to control snails.

Chlortalonil (algicide) (tetrachloroisophthalonitrile): used at 1-2 lbs/acre (1.1-2.2 kg/ha).

Battino-Viterbo et al. (1973) *In vitro*, 5 ppm is algicidal to *Anabaena* but 16 ppm had no effect on *Chlorella*.

Minervini Ferrante et al. (1974) *In vitro*, 50 percent inhibition of growth was at 10 ppm for *Oscillatoria* (44 percent) and > 16 ppm for *Cylindrospermum*, algicidal concentration was > 16 ppm for *Oscillatoria* and *Cylindrospermum*.

Copper chloride (algicide) ( $\text{CuCl}_2$ )

Kumar et al. (1985) *In vitro*, 0.2 ppm  $\text{CuCl}_2$  had no significant effect on BNF by *Nostoc linkia*; 2 ppm caused about 20 percent inhibition in nitrogen fixation; 20 ppm caused about 50 percent inhibition in BNF and  $\text{H}_2$  production.

Copper sulphate (fungicide, algicide): used at 1–25 lbs/acre (1.1–2.6 kg/ha).

Das (1976)

Dunigan and Hill (1978), *In situ*, 2 ppm Cu in the floodwater at the beginning of the crop when no floating algae were present permitted to control algal weeds.

Dunigan et al. (1979)

Gibson (1972) *In vitro*, 1 ppm was algicidal to *Anabaena flos-aquae* but 4 ppm only caused a partial inhibition of *Senedesmus quadricauda*.

Mukherji (1968)

Mukherji and Laha (1979) *In situ*, 12 kg/ha was algicidal to *Chara* and *Nitella*.

Mukherji and Sengupta (1964) *In situ*, 9–11 kg/ha could control *Chara* at the initial stage but there was no residual effect.

Pande et al. (1981) *In vitro*,  $\text{LC}_{50}$  for *Spirulina platensis* was 0.7 ppm Cu after 96 h. 0.5 ppm had no significant effect.

Copper dimethyl dithiocarbamate (?):

Padhy (1985)

Copper oxychloride, Blitox (fungicide) (dicopper chloride trihydroxide): Foliage fungicide applied at 2–5 lbs/acre (2.2–5.5 kg/ha).

Gangawane et al. (1982) *In vitro*, 10 ppm was not inhibitory to *Nostoc* sp. and *Tolypothrix tenuis*.

Padhy (1985)

Vaishampayan and Prasad (1982)

Cotoron: see Fluometuron

Cyanazine (herbicide) (2-(4-chloro-6-ethylamino-1,3,5-triazin-2-ylamino)-2-methylpropionitrile): pre-and post-emergence use at 1–3 kg ai/ha, short persistence.

Holst et al. (1982) *In vitro*, after 10 days, 0.1 ppm had no effect on *Azolla* sp. growth on  $\text{N}_2$ , 1 and 10 ppm caused a partial inhibition.

Cypermethrin (insecticide) (alpha-cyano-3-phenoxyphenyl-3 (2,2-dichlorovinyl)-, 2-dimethyl cyclopropane carboxylate).

Megharaj et al. (1988) *In vitro*, no marked inhibition of *Nostoc linckia* by Cypermethrin was observed till 50 ppm.

Megharaj et al. (1989) *In vitro*, Cypermethrin had no effect at 5 ppm on the growth of *Scenedesmus bijugatus* measured after 20 d; 25 ppm caused a 40 percent inhibition. 10 ppm had no effect on the growth of *Synechococcus elongatus* and 25 ppm caused a 26 percent inhibition.

Dalapon (herbicide) (2,2-dichloropropionic acid): used at 0.75–20 lbs/ha (1–22 kg/ha) on many crops.

Padhy (1985)

Pillay and Tchan (1972) *In vitro*, 1 and 5 ppm had no effect on the growth of *Chlorella* sp., *Scenedesmus* sp., *Chlorococcum* sp., *Chlamydomonas* sp., *Euglena* sp., *Botrydiopsis* sp., *Nostoc* sp., *Anabaena* sp.

Venkataraman and Rajylakswami (1971) *In vitro*, 23 strains of BGA could grow at 100 ppm, one at 10 ppm, and 3 at 1 ppm.

DCA (?) (2–3-dichloroaniline):

Padhy (1985)

DCMU: see Diuron

DDE: see DDT

DDT, DDE (insecticide) (major component 1,1,1-trichloro-2,2bis (4-chlorophenyl) ethane): used at 1–2 lbs/acre (1.1–2.2 kg/ha).

Batterton et al. (1972)

Chaudhari et al. (1989) *In vitro* 5 ppm inhibited *Scenedesmus* growth by 42 percent. *Chlorella* and *Spirulina* were tolerant at all doses of DDT.

Goulding and Ellis (1981) *In vitro*, whereas the growth of *Anabaena variabilis* was unaffected by 1 ppm DDT, the growth of *Chlorella fusca* was affected by 0.1 ppm.

Hotter et al. (1979) *In vitro*, the concentration causing a 50 percent reduction of photoautotrophic growth *in vitro* was 4 ppm for *Aphanocapsa* 6714, 100 ppm for *Aphanocapsa* 6308, 100 ppm for *Anabaena variabilis*, and 50 ppm for *Nostoc* sp.

Kikuchi et al. (1984) *In vitro*, EC<sub>50</sub> was > 100 ppm for *Chlorella vulgaris*, 4 ppm for *Nitzschia closterium* and 9 ppm for *Anabaena flos-aquae*.

Padhy (1985)

Subba-Rao and Alexander (1980) *In vitro*, 1 to 10 ppm had no marked effect on the chlorophyll content and biomass of *Chlorella vulgaris* measured as the average values and concentration in 8 and 13 days cultures. *In vitro*, 1 to 10 ppm had no marked effect on soil respiration measured for two to three days after pesticide application with classical respirometric techniques on 0.5 g of soil.

Vance and Drummond (1969) *In vitro*, lethal dose was > 15 ppm for *Anabaena cylindrica* and > 20 ppm for *Microcystis aeruginosa*, *Senedesmus quadricauda* and *Oedogonium* sp.

Deltan (?) (?):

Bongale (1985) *In vitro* 150 ppm was agicidal for *Hapalosiphon* sp. and *Nostoc microscopicum*.

Diazinon (insecticide, molluscicide, grazer control) (O,O-diethyl O-2-isopropyl-6-methylpyrimidin-4-yl phosphorothioate): used at 0.25–2 lbs/acre (0.3–2.2 kg/ha).

Ahmad and Venkataraman (1973) *In vitro*, no detrimental effect on *Aulosira fertilissima* at the recommended dose.

Mallison and Cannon (1984)

Padhy (1985)

P.K. Singh (1973) *In vitro*, at 18 days, 100 ppm had no effect on *Cylindrospermum*, *Aulosira fertilissima* and *Plectonema boryanum*.

Sinha et al. (1986) 50 ppm is needed for molluscicide use.

Srinivasan (1981) *In situ*, 3 kg/ha significantly increased the production of BGA in inoculum production plots.

Dicamba (herbicide) (3,6-dichloro-o-anistic acid): Foliar-or soil-applied herbicide, readily absorbed by leaves and roots and translocated throughout the plant. Dosage varies with specific use and ranges from 0.1 to 11 kg ai/ha.

Holst et al. (1982) *In vitro*, at 10 days, 10 ppm did not inhibit *Azolla* sp. growth on N<sub>2</sub>.

Dichlone (fungicide) (2,3-dichloro-1,4-naphthoquinone): Superseded compound. Used in swimming pools to control certain blue-green algae. Used at 0.25–0.5 lbs/acre (0.3–0.6 kg/ha).

Das (1976)

Fitzgerald and Skoog (1954)

Kashyap and Gupta (1981) *In vitro*, 0.1 to 0.5 ppm was partially inhibitory to *Nostoc muscorum*, *N. calcicola*, and *Anacystis nidulans*, 1 ppm was algicidal; *Anabaena cylindrica* tolerated concentrations 10 times higher.  
Padhy (1985)

Dichlorophen, Panacide (fungicide, bactericide) (4,4'-dichloro-2,2'-methylene diphenol): applied at ? kg/ha.

Battino-Viterbo et al. (1973) *In vitro* is not algicidal at 14 ppm for *Anabaena* and *Chlorella*.

Gupta and Saxena (1974) *In vitro*, concentrations higher than 20 ppm were strongly inhibitory to *Scenedesmus*, *Chlorella*, *Myxosarcina* and *Aulosira*. 10 ppm was algicidal to *Nostoc* sp.

Minervini Ferrante et al. (1974) *In vitro*, 50 percent inhibition of growth was 2 ppm for *Oscillatoria* (44 percent) and between 8 and 16 ppm for *Cylindrospermum*, algicidal concentration was 4 ppm for *Oscillatoria* and > 16 ppm for *Cylindrospermum*.

Padhy (1985)

Dicofol, Kelthane (insecticide) (2,2,2-trichloro-1, 1-bis (4-chlorophenyl) ethanol): Non-systemic acaricide with little insecticidal activity used at 0.56–4.5kg ai/ha.

Mallison and Cannon (1984)

Dieldrin (insecticide) ((IR,4S,4aS,5R,6R,7S,8S,8aR)-1,2,3,4,10, 10-hexachloro-1,4,4a,5,6,7,8,8a-octahydro-6,7-epoxy-1,4:5,8-dimethanonaphthalene): Non-systemic and persistent insecticide of high contact and stomach activity to most insects. used at ? kg/ha (not used in US).

Batterton et al. (1971)

Padhy (1985)

Schauberger & Wildman (1977) *In vitro*, 10 ppm had no effect on *Anabaena cylindrica*, *Anacystis nidulans* and *Nostoc muscorum*; 50 percent inhibition was at > 50 ppm; 1000 ppm was not lethal.

Vance and Drummond (1969) *In vitro*, lethal dose was >15 ppm for *Anabaena cylindrica*, < 5 ppm for *Microcystis aeruginosa*, and >20 ppm for *Scenedesmus quadricauda* and *Oedogonium* sp.

Diflubenuron, Dimilin (insecticide) (1-(4-chlorophenyl)-3-(2,6-difluorobenzoyl) urea): used at 0.02–0.14 lbs/acre (0.022–0.16 kg/ha).

Padhy (1985)

Wurtsbaugh and Apperson (1978)



Difolatan: see Captafol

Digust (?) (?):

DaSilva et al. (1974)

Dimethoate, Rogor (insecticide, acaricide) (O,O-dimethyl S-methylcarbamoylmethyl phosphorodithioate): Contact and systemic pesticide effective at 0.3–0.7 kg ai/ha.

Adhikari (1989) Rogor had no significant effect on *Westiellopsis prolifica* growth measured *in vitro* 15 d after inoculation until 15 ppm, 50 percent inhibition was at 30 ppm, total inhibition was at 300 ppm.

Bongale (1985) *In vitro* 10 ppm had no significant effect on *Hapalosiphon* sp. and *Nostoc microscopicum*.

Shivaram and Shetty (1988) *In vitro*, 6 ppm had no significant effect at 30 days on the dry weight of *Anabaena variabilis*, *Calothrix* sp., and *Cylindrospermum musicola*, and decreased it by about 20 percent in *Hapalosiphon welwitschii*, *Nostoc* sp. and *Scytonema hofmani*. 50 percent inhibition was observed at about 8 ppm for this three last strains. Sensitivity was higher when N<sub>2</sub>-fixation was considered but was not significantly affected at 2 ppm.

Dimilin: see Diflubenzuron

Dinoseb, Dinoterb (herbicide) (2-sec-butyl-4,6-dinitrophenol): contact herbicide used at 2–4 kg ai/ha.

Hawxby et al. (1977) *In vitro*, concentrations up to 10 mol had no effect on *Chlorococcum* and *Anabaena* while 10 mol reduced *Lyngbia* growth by 50 percent and completely inhibited *Chlorella* growth.

Holst et al. (1982) *In vitro*, after 10 days, 0.1 ppm partially inhibited *Azolla* sp. growth on N<sub>2</sub>, 1 ppm caused a total inhibition.

Khalil et al. (1980) 10 ppm was not algicidal for *Nostoc* sp., *Tolypothrix tenuis* and *Mastigocladus laminosus* but caused inhibition in growth by 60–80 percent.

Wegener et al. (1985) In experiments with 23 g of non submerged soil, dinoseb acetate at recommended doses for field application inhibited algal growth and BNF for about two months.

Dinoterb: see Dinoseb

Diphenamid, Enide (herbicide) (N,N-dimethyldiphenylacetamide): Selective pre-emergence herbicide used to control grass and broad-leaved weeds at 4–6 kg ai/ha.

Mallison & Cannon (1984) as Enide

Diquat (herbicide, algicide) (9,10-dihydro-8a, 10a-diazoniaphenanthrene): applied at 1–2 kg/ha for aquatic weeds.

Das (1976)

DaSilva et al. (1975) *In vitro*, 20 ppm inhibited BNF by 9/9 BGA strains.

Holst et al. (1982) *In vitro*, at 10 days, 0.1 ppm partially inhibited *Azolla* sp. growth on N<sub>2</sub>, 1 ppm caused a total inhibition.

Padhy (1985)

Dithane: see Mancozeb

Diuron, DCMU (herbicide) (3-(3,4-dichlorophenyl)-1,1-dimethylurea): Inhibits photosynthesis and is used for general weed control on non-crop areas at 10–30 kg ai/ha and 0.6–4.8 kg ai/ha on crops.

Addison and Bardsley (1968)

Amla and Kochhar (1982)

Allen et al. (1983)

Das (1976)

Hotter et al. (1979) *In vitro*, the concentration causing a 50 percent reduction of photoautotrophic growth was 0.01 ppm for *Aphanocapsa* 6714, 0.12 ppm for *Aphanocapsa* 6308, 0.01 ppm for *Anabaena variabilis*, and 0.05 ppm for *Nostoc* sp.

Mallison and Cannon (1984) *In vitro* at 14 d, was lethal to *Plectonema borianum*.

Maule and Wright (1984) *In vitro* experiment with seven green algae and six BGA, EC50 values were lower than 0.6 ppm in all cases.

Padhy (1985)

Pal and Chatterjee (1987) 10 ppm controlled seed formation in *Chara*, 50 ppm was toxic within 24 h of treatment.

Pillay and Tchan (1972) *In vitro*, 1 ppm partially inhibited the growth of *Chlorella* sp., *Scenedesmus* sp., *Chlorococcum* sp., *Chlamydomonas* sp., *Euglena* sp., *Botrydiopsis* sp., *Nostoc* sp., *Anabaena* sp. 5 ppm was lethal to *Chlorella* sp. and *Euglena* sp. and partially inhibited *Botrydiopsis* sp., *Nostoc* sp., *Anabaena* sp.

Pipe and Cullimore (1980) Small scale experiments (200 ml flasks) with

soil showed that 1 ppm decreased algal abundance by about 200 times in the first cm of a clay soil.

Vaishampayan (1984) Isolation of a mutant resistant to Diuron.

Venkataraman and Rajylakswami (1971) 14 strains of BGA could grow at > 100 ppm, five at 5–10 ppm.

Duter: see Fentin hydroxide

Ekalux: see Quinalphos

Endotaf: see Endosulfan

Endosulfan (insecticide, molluscicide) (C,C'-(1,4,5,6,7,7-hexachloro-8,9,10-trinorbon-5-en-2,3-ylene) (dimethyl sulphite) 6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzoxathiepin 3-oxide): used at 0.2–4 lbs/acre (0.22–4.4 kg/ha).

Adhikari (1989) *In vitro*, endotaf had no significant effect on *Westiellopsis prolifica* growth measured *in vitro* 15 d after inoculation until 6 ppm, 50 percent inhibition was at 15 ppm, total inhibition was at 300 ppm.

Sardespande and Goyal (1982) *In vitro*, 1–50 ppm partially inhibited N accumulation by *Anabaena iyengarii*, *Hapalosyphon intricatus*, *Calothrix membranacea* and *Calothrix bharadwaja*. 50 percent inhibition was observed between 1 and 5 ppm.

Sinha et al. (1986) 10 ppm is needed for molluscicide use.

Endrin (insecticide) ((1R,4S,4aS,5S,7R,8R,8aR)-1,2,3,4,10,10-hexachloro-1,4,4a,5,6,7,8, 8a-octahydro-6,7-epoxy-1,4:5,8-dimethanonaphthalene): foliar insecticide which acts against a wide range of pests. Used at 0.2–0.5 kg ai/ha on upland rice.

Ahmad and Venkataraman (1973) *In vitro*, no detrimental effect on *Aulosira fertilissima* when used at the recommended dose.

Batterton et al. (1971)

Padhy (1985)

P.K. Singh (1973) *In vitro*, at 18 days, 100 ppm had no effect on *Cylindrospermum*, *Aulosira fertilissima* and *Pleconema boryanum*.

Vance and Drummond (1969)

Enide: see Diphenamid

Ethephon, Ethel (plant growth regulator) (2-chloroethylphosphonic acid): Used to accelerate the pre-harvest ripening of fruit and vegetables.

Hotter et al. (1979) *In vitro*, the concentration causing a 50 percent reduction of photoautotrophic growth *in vitro* was 200 ppm for *Aphanocapsa* 6714, 500 ppm for *Aphanocapsa* 6308, 200 ppm for *Anabaena variabilis*, and > 1000 ppm for *Nostoc* sp.

Ethirimol, Milstem (Fungicide) (IUPAC 5-butyl-2-ethylamino-6-methylpyrimidin-4-01): Systemic fungicide effective against powdery mildews of cereals and other crops. Used at 0.5–1 lbs/acre (0.7–1.1 kg/ha).

Hotter et al. (1979) *In vitro*, the concentration causing a 50 percent reduction of photoautotrophic growth *in vitro* was > 100 ppm for *Aphanocapsa* 6714, >100 ppm for *Aphanocapsa* 6308, 100 ppm for *Anabaena variabilis*, and 50 ppm for *Nostoc* sp.

Ethel: see Ethephon

EPTC (herbicide) (S-ethyl dipropyl (thiocarbamate): Kills germinating weed seeds and inhibits bud development from underground portions of perennial weeds. Used at 3–6 kg ai/ha.

Padhy (1985)

Fenitrothion (Insecticide) (O,O-dimethyl O-(3-methyl-4-nitophenyl) phosphorothioate)

Kikuchi et al. (1984) *In vitro*, EC<sub>50</sub> in ppm was > 100 for *Chlorella vulgaris*, 4 for *Nitzschia closterium* and 9 for *Anabaena flos-aquae*.

Fentin acetate, Brestan (fungicide, algicide) (IUPAC triphenyltin(IV) acetate): non-systemic, used at 160–260 g ai/ha.

Battino-Viterbo et al. (1973) *In vitro* 0.75 ppm is algicidal to *Anabaena* and 1 ppm to *Chlorella*

Bisiach (1972a, b) *In vitro*, 1 ppm is algicidal to *Spirogyra*, *Oedogonium* and *Hydrodictyon*.

Das (1976)

Minervini Ferrante et al. (1974) *In vitro*, 0.1 ppm partly inhibited the growth of *Oscillatoria* (44 percent) and *Cylindrospermum*, 0.5 ppm totally inhibited growth

Mukherji (1968)

Mukherji and Laha (1969) *In vitro*, 0.48 ppm was algicidal to *Chara* sp.

Mukherji and Ray (1966) *In situ*, 1.75 kg/ha controlled *Chara*.

Fentin hydroxide, Duter (fungicide) (triphenyltin hydroxide): Non-systemic fungicide for the control of early and late blights of potato at 250–350 g ai/ha.

Gangawane and Kulkarni 1979

Fenuron (herbicide) (1,1-dimethyl-3-phenylurea):

Das (1976)

Fenvalerate (Insecticide) (Cyano(3-phenoxyphenyl)-methyl)-methyl 4-chloro-alpha- (1-methylethyl) benzene acetate)

Megharaj et al. (1988) *In vitro*, no marked inhibition of *Nostoc linckia* was observed till 50 ppm.

Megharaj et al. (1989) *In vitro*, Fenvalerate had no effect at 10 ppm on the growth of *Scenedesmus bijugatus* measured after 20 d; 25 ppm caused a 10 percent inhibition. 25 ppm had no significant effect on the growth of *Synechococcus elongatus*.

Ferbam (fungicide) (iron tris [dimethyldithiocarbamate]): used for the protection of foliage against fungal pathogens at 175 g/100 l or 1–15 lbs/acre (1.1–16 kg/ha).

Das (1976)

Fernoxone (herbicide) (?): used at 20 kg formulation/ha.

Srinivasan and Ponnuswami (1978) single dose of the formulation reduced the production of BGA in inoculum multiplication plots by 25 percent.

Fluchloralin (herbicide) (N-(2-chloroethyl)-trifluoro-2,6-dinitro-N-propyl-p-toluidine): Preplanting or pre-emergence herbicide effective against grasses and broad-leaved weeds at 0.5–1 kg ai/ha depending on the crop and soil type.

Khalil et al. (1980) *In vitro*, 50 ppm was not algicidal for *Nostoc* sp., *Tolypothrix tenuis* and *Mastigocladus laminosus* but caused partial inhibitions of growth by about 70 percent.

Kumar and Singh (1981) *In vitro* at 10 days of growth, 20–30ppm caused partial growth inhibition in *Anabaena doliolum* and *Nostoc linckia*; 40 ppm was lethal.

D.T. Singh et al. (1987)

L.J. Singh et al. (1986) *In vitro*, 20 ppm had no effect on *Gloeocapsa* but 10 ppm inhibited *Nostoc muscorum* by 75 percent.

Srinivasan and Ponnuswami (1978) *In situ*, double dose of the formulation

(Basalin 48 percent 3 l/ha) had no effect on the production of BGA in inoculum multiplication plots.

Fluometuron, Cotoron (herbicide) (1,1-dimethyl-3-(3-trifluoro-m-tolyl) urea): mainly absorbed through the roots, weak activity through foliage. Used at 1.0–1.5 kg ai/ha.

Hawxby et al. (1977) *In vitro*, 1 mol inhibited *Lyngbia*, *Anabaena* and *Chlorella* growth by 50–75 percent but not *Chlorococcum*.

Mallison and Cannon (1984) *In vitro* at 31 days, 10 ppm inhibited the growth of *Plectonema borianum* by 10 percent.

Padhy (1985)

Venkataraman and Rajylakswami (1971) 21 strains of BGA could grow at > 100 ppm, two at 10 ppm and one at 1 ppm.

Fluorodifen (herbicide) (4-nitrophenyl alpha, alpha, alpha-trifluoro-2-nitro-p-tolyl ether): Pre- and post-emergence contact herbicide used at 3–4 kg ai/ha.

El-Sawy et al. (1984) In pot, 3 kg/ha had no effect on inoculated *Nostoc muscorum* and *Anabaena oryzae*.

Folpet (Fungicide, algicide) (?): used at 2–10 lbs/acre (2.2–11 kg/ha).

Bisiach (1972a, b) *In vitro*, 4 ppm is algicidal for *Spirogyra*, *Oedogonium* and *Hydrodictyum*.

Padhy (1985)

Fytolan (Fungicide) (copper oxychloride): used at 2–5 lbs/acre (2.2–5.5 kg/ha).

Gangawane (1980) *In vitro*, tolerant concentrations were 100 ppm for *Westiellopsis* sp., 100 ppm for *Aulosira* sp., 500 ppm for *Nostoc* sp., 500 ppm for *Tolypothrix* sp. and 100 ppm for *Calothrix* sp.

Padhy (1985)

Furadan: see Carbofuran

Gamma BHC: see BHC

Gamma HCH, HCH, Lindane: (insecticide, grazer control) (hexachloro-cyclohexane [mixed isomers]): used at 0.25–4 lbs/acre (0.3–4.4 kg/ha).

Ahmad and Venkataraman (1973) *In vitro* no detrimental effect on *Aulosira fertilissima* when used at the recommended dose.

Das and Singh (1978a).

Das and Singh (1978b) *In vitro*, 60 ppm was inhibitory for *Anabaena raciborskii* and *A. aphanizomenoides*, 10 ppm was algistatic.

Kar and Singh (1979a, b) Depending on the level of nutrients in the medium, inhibition of the growth of *Nostoc muscorum* measured at 10 days was 8–57 percent with 2 ppm, 47–81 percent with 3 ppm, and 54–91 with 4 ppm.

Padhy (1985)

Sharma and Gaur (1980) Four strains of *Nostoc* sp. and one strain of *Aulosira fertilissima* tolerated 5–7 ppm in combination with other pesticides, three strains of *Aulosira fertilissima* tolerated 10 ppm.

Sharma and Gaur (1982)

Sharma (1984)

P.K. Singh (1973) *In vitro*, at 18 days, had no effect on *Cylindrospermum* at 80 ppm and on *Aulosira fertilissima* and *P. boryanum* at 200 ppm.

Glyphosate (herbicide) (N-[phosphonomethyl] glycine): Non selective post-emergence herbicide, used at 0.3–2.24 kg ai/ha.

Hotter et al. (1979) *In vitro*, the concentration causing a 50 percent reduction of photoautotrophic growth *in vitro* was 100 ppm for *Aphanocapsa* 6714, 2 ppm for *Aphanocapsa* 6308, 2 ppm for *Anabaena variabilis*, and 2 ppm for *Nostoc* sp.

Maule and Wright (1984) *In vitro* experiment with 7 green algae and 6 BGA, EC50 values ranged from 70 to 600 ppm.

Goltix: see Metamitron

Hexacap: see Captan

HOE 2997 (algicide) (2-dichloroacetamide-3-chloro- 1,4-naphtoquinone): used at? kg/ha).

Battino-Viterbo et al. (1973) *In vitro*, is algicidal at 1 ppm for *Anabaena* and at more than 2 ppm for *Chlorella*.

Bisiach (1972a, 1972b) *In vitro* 2 ppm is algicidal for *Spirogyra*, and 1 ppm for *Oedogonium* and *Hydrodictyon*.

Das (1976)

Minervini Ferrante et al. (1974) *In vitro*, 50 percent inhibition of growth was at 2 ppm for *Oscillatoria* (44 percent) and 1 ppm for *Cylindrospermum*, algicidal concentration was 8 ppm for *Oscillatoria* and 2 ppm for *Cylindrospermum*.

Padhy (1985)

Iprodione, Rovral (fungicide) (3-(3,5-dichlorophenyl)-N-isopropyl-2,4-dioxo-imidazolidine-1-carboxamide): used at 0.5–1.0 kg ai/ha.

Gangawane and Kulkarni (1979) *In vitro*, concentrations < 500 ppm had no effect on *Westiellopsis* sp., *Aulosira* sp., *Calothrix* sp., *Nostoc* sp., and *Tolypothrix* sp.

Isotox: see Gamma HCH

Kelthane: see Dicofol

K-Lox (algicide) (organic copper chelate): used at ? ? kg/ha.

Dunigan and Hill (1978)

Dunigan et al. (1979) *In situ*, 2 ppm Cu prevented algal growth if applied when no algae were blooming.

Lasso: see Alachlor

Lindane: see HCH

Linuron (herbicide) (3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea): used at 0.5–3 lbs/acre (0.6–3.4 kg/ha)

DaSilva et al. (1974)

DaSilva et al. (1975) *In vitro*, 10 ppm inhibited BNF by 4 of 9 strains of BGA and stimulated BNF by other strains after a temporary partial inhibition.

Holst et al. (1982) *In vitro*, after 10 days, 0.1 and 1 ppm caused a partial inhibition of *Azolla* sp. growth on N<sub>2</sub>, 10 ppm caused a total inhibition

Padhy (1985)

Venkataraman and Rajylakswami (1971) 15 strains of BGA could grow at > 100 ppm, 6 at 5–10 ppm, and two at 1 ppm.

Machete: see Butachlor

Magnacide-H (herbicide) (2-propenal): applied as aquatic herbicide up to 50 ppm.

Fritz-Sheridan (1982) *In vitro*, 0.5 ppm had no effect on O<sub>2</sub> evolution by *Anabaena* sp., 2 ppm was algicidal.

Padhy (1985)

Malathion (insecticide) (diethyl (dimethoxythiophosphorylthio) succinate): used at 0.5–3 lbs/acre (0.55–3.3 kg/ha).



DaSilva et al. (1974)

DaSilva et al. (1975) *In vitro*, 100 ppm caused partial inhibition of BNF followed by stimulation in 6 of 9 strains of BGA.

Mallison and Cannon (1984) *In vitro* at 31 days, 10 ppm did not inhibit the growth of *Plectonema borianum*.

Padhy (1985)

Tandon et al. (1988) *In vitro*, *Anabaena* survived up to 500 ug/ml of malathion. *Aulosira* recovered to control levels only at 10 ppm.

Tiwari et al. (1979)

Mancozeb, Dithane (fungicide) (manganese ethylenebis (dithiocarbamate) (polymeric) complex of Zn and Maneb containing 20 percent Mn and 2.5 percent Zn): Protectant fungicide generally used at 1.4–1.9 kg ai/ha.

Bharati and Angadi (1980)

Bongale (1985) *In vitro*, 150 ppm was algicidal for *Hapalosiphon* sp. and *Nostoc microscopium*.

Mukerji (1968)

Mukerji and Laha (1979) *In situ*, 6.25 kg/ha was algicidal in 21 days for *Chara* and *Nitella*.

Padhy (1985)

Shivaram and Shetty (1988) *In vitro*, 9 ppm had no negative effect at 30 days on the dry weight of *Anabaena variabilis*, *Calothrix* sp., *Cylindrospermum musicola*, *Hapalosiphon welwitschii*, *Nostoc* sp. and *Scytonema hofmani*. Some enhancement of N<sub>2</sub> fixed was observed at 3–9 ppm.

Subramanian (1982) *In vitro*, 7.5 ppm had no effect on 4 strains of *Anabaena*, 75 ppm was lethal.

Venkataraman and Rajylakswami (1971) concentrations of 50 ppm allowed the growth of 17/27 strains of BGA, 5 ppm the growth of 5/27 strains.

Maneb (fungicide) (manganese ethylenebis (dithiocarbamate) [polymeric]): Protectant fungicide used at 1.5–2.0 g/l to control many fungal diseases.

Padhy (1985)

MBC: see Carbendazim

MCPA (herbicide) (4-chloro-o-tolyloxyacetic acid): Hormone-type selective herbicide used at 0.28–2.25 kg ai/ha.

Ahmad and Venkataraman (1973) no detrimental effect on *Aulosira fertilissima* when used at the recommended dose, 100 ppm was not detrimental.

DaSilva et al. (1974)

DaSilva et al. (1975) *In vitro*, 25 ppm inhibited BNF by 8 of 9 strains of BGA.

Hotter et al. (1979) *In vitro*, the concentration causing a 50 percent reduction of photoautotrophic growth *in vitro* was >1,000 ppm for *Aphanocapsa* 6,7 14, >1,000 ppm for *Aphanocapsa* 6308, 400 ppm for *Anabaena variabilis*, and 100 ppm for *Nostoc* sp.

Inger (1970) *In vitro*, affect the growth of *Nostoc muscorum*, *Nostoc punctiforme* and *Cylindrospermum* at concentrations recommended for field application, but was stimulatory at low concentrations— $10^{-4}$ – $10^{-5}$  M.

Maule and Wright (1984) *In vitro* experiment with 7 green algae and 6 BGA, EC50 values ranged from 90 to 300 ppm.

Padhy (1985)

Smith et al. (1977) *In situ*, control of BGA was not achieved with 2–3 ppm

MCPB (herbicide) (4-(4-chloro-o-tolyloxy) butyric acid): Selective post-emergence herbicide used at 1.7–3.4 kg ai/ha.

Ahmad and Venkataraman (1973) no detrimental effect on *Aulosira fertilissima* when used at the recommended dose, and at 100 ppm.

Padhy (1985)

MCPP: see Mecoprop

Mecoprop, MCPP (herbicide) ((±)-2-(4-chloro-o-tolyloxy) propionic acid): Systemic hormone-type post-emergence herbicide used at 1.5–2.7 kg/ha.

Hotter et al. (1979) *In vitro*, the concentration causing a 50 percent reduction of photoautotrophic growth *in vitro* was 250 ppm for *Aphanocapsa* 6714, 1000 ppm for *Aphanocapsa* 6308, 100 ppm for *Anabaena variabilis*, and 100 ppm for *Nostoc* sp.

Mephosfolan (insecticide) (diethyl 4-methyl-1,3-dithiolan-2-ylidenephosphor amide): used at ? kg/ha.

Srinivasan (1981) *In situ*, 1.5 kg/ha significantly increased the production of BGA in inoculum production plots.

Metalaxyl (fungicide) (methyl N-(2-methoxyacetyl)-N-(2,6-xylyl)-DL-alaninate): used at ? kg/ha.

Mallison and Cannon (1984)

Metamitron (Herbicide) (4-amino-3-methyl-6-phenyl-1,2,4-triazine-5-(4H)-one): DCMU type herbicide used at 3.5–7 kg ai/ha

Gadkari (1987) *In vitro* 35 ppm ai was inhibitory to *Anabaena cylindrica* but 35 and 70 ppm ai was not inhibitory to *Nostoc muscorum*.

Metasystox R: see Oxydemeton-methyl

Metham, Vapam (fungicide) (methylthiocarbamic acid): used at ? kg/ha.  
Padhy (1985)

Methomyl (Insecticide)

Khalil and Mostafa (1986) *In vitro*, no significant effect on the growth of *Phormidium fragile* up to a concentration of 112 ppm.

2-methoxyethylmercury chloride, Agallol (fungicide): Used at ? kg/ha.  
Bharati and Angadi (1980)

Methoprene (insecticide) (isopropyl (E-E)-(RS)-11-methoxy-3,7,11-trimethyldeca-2,4-dienoate): used at 15–20 g/ha.

Padhy (1985)  
Wurtsbaugh and Apperson (1978)

Methoxychlor (insecticide) (1,1, 1-trichloro-2,2-bis(4-methoxyphenyl) ethane): used at 0.25–0.50 lbs/acre (0.3–0.6 kg/ha).

Padhy (1985)  
Wurtsbaugh and Apperson (1978)

Metolachlore (herbicide) (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide): Germination inhibitor active on grasses at 1.0–2.5kg ai/ha.

Mallison and Cannon (1984)

Metribuzin (herbicide) (4-amino-6-tert-butyl-3-methylthio-1,2,4-triazin-5(4H)-one): used at 0.3–1 lbs/acre (0.4–1.1 kg/ha)

Arvik et al. (1973) *In vitro*, 1 ppm was algicidal to *Schizothrix calcicola*, *Anabaena* sp., *Chlorella vulgaris*, *Chlamydomonas* sp. and *Chlorococcum* sp., 0.05 ppm had a slight inhibitory effect  
Gadkari (1987) *In vitro*, 7 ppm.ai was inhibitory to *Anabaena cylindrica* but concentrations up to 70 ppm had no effect on *Nostoc muscorum*.

Holst et al. (1982) *In vitro*, after 10 days, 10 ppm caused a partial inhibition of *Azolla* sp. growth on N<sub>2</sub>.

Padhy (1985)

Mexacarbate (insecticide) (4-dimethylamino-3,5-xylyl methylcarbamate): Superseded compound. Used at ? kg/ha).

Padhy (1985)

Milstem: see Ethirimol

MnO<sub>4</sub>K (algicide):

Bisiach (1972a, b) *In vitro*, 8 ppm is algicidal for *Spirogyra*, *Oedogonium* and *Hydrodictyon*.

Molinate, Ordram (herbicide) (S-ethyl azepane-1-carbothioate): Toxic to germinating broad-leaved and grassy weeds. Used at 2–4 kg ai/ha.

El-Haddad (1984) *In vitro*, 10 ppm had no effect on growth and BNF of *Nostoc muscorum* and *Anabaena oryzae*.

El-Sawy et al. (1984) In pot, 5 kg/ha had no effect on inoculated *Nostoc muscorum* and *Anabaena oryzae*.

Hamdi et al. (1970) *In vitro*, 0.25 ppm, 30 percent inhibition; 2.5 ppm, 30 percent inhibition; 25 ppm 80 percent inhibition on cultures of *Tolypothrix tenuis*.

Padhy (1985)

Smith et al. (1977) *In situ*, control of BGA and green algae was not achieved with 2–3 ppm.

Monocrotophos (insecticide) (dimethyl (E)-1-methyl-2-(methylcarbamoyl) vinyl phosphate): used at 0.5–1 lbs/acre (0.55–1.1 kg/ha). Fast-acting insecticide with both systemic and contact action, used at 250–500 g ai/ha against mites and sucking insects and 500–1000 g ai/ha against lepidopterous.

Bongale (1985) *In vitro*, 30 ppm have no inhibitory effect on *Hapalosiphon* sp. and *Nostoc microscopicum*.

Megharaj et al. (1988) *In vitro* 5 ppm inhibited growth of *Nostoc linckia* by 25 percent at and by 50 percent at 100 ppm

Megharaj et al. (1989) *In vitro*, monocrotophos had no effect at 10 ppm on the growth of *Scenedesmus bijugatus* measured after 20 d; 25 ppm caused a 40 percent inhibition. 25 ppm had no significant effect on the growth of *Synechococcus elongatus*.

Monuron (herbicide, algicide) (3-(4-chlorophenyl)- 1,1 -dimethylurea): Inhibitor of photosynthesis absorbed via the roots. Used at 10-30 kg ai/ha in noncrop areas.

Addison and Bardsley (1968)

Amla and Kochhar (1982)

Das (1976)

DaSilva et al. (1974)

DaSilva et al. (1975) *In vitro*, 10 ppm inhibited BNF by 9 of 9 strains of BGA.

Padhy (1985)

Pillay and Tchan (1972) *In vitro*, 1 ppm partially inhibited the growth of *Chlorella* sp., *Scenedesmus* sp., *Chlorococcum* sp., *Chlamydomonas* sp., *Euglena* sp., *Botrydiopsis* sp., *Nostoc* sp., *Anabaena* sp. 5 ppm was lethal to *Chlorella* sp. and *Euglena* sp. and partially inhibited *Botrydiopsis* sp., *Nostoc* sp., *Anabaena* sp.

Vaishampayan (1984)

Vaishampayan (1985) 68 ppm fully inhibited a parent strain of *Nostoc muscorum* but a spontaneous mutant could support about 85 ppm.

Nabam (fungicide, algicide) (disodium ethylenebis [dithiocarbamate]): used at ? kg/ha).

Padhy (1985)

NAC: see Carbaryl

Naptalam (herbicide) (N-1 -naphthylphthalamic acid): Inhibits seed germination. Used at 2.0-5.5 kg/ha.

Holst et al. (1982) *In vitro*, at 10 days, 10 ppm did not inhibit *Azolla* sp. growth on N<sub>2</sub>.

Neburon (herbicide) (1-butyl-3-(3,4-dichlorophenyl)-1 -methylurea): inhibits photosynthesis, is absorbed through plant roots and is used at 2-3 kg ai/ha.

Padhy (1985)

Pillay and Tchan (1972) *In vitro*, 1 ppm partially inhibited the growth of *Chlorella* sp., *Scenedesmus* sp., *Chlorococcum* sp., *Chlamydomonas* sp., *Euglena* sp., *Botrydiopsis* sp., *Nostoc* sp., *Anabaena* sp. 5 ppm was lethal to *Chlorella* sp. and *Euglena* sp. and partially inhibited *Botrydiopsis* sp., *Nostoc* sp., *Anabaena* sp.

Nitrofen (herbicide) (2,4-dichlorophenyl 4-nitrophenyl ether): selective herbicide, toxic to a number of broad-leaved and grass weeds, and used at 2 kg ai/ha.

Das (1976)

Mukerji (1968)

Srinivason and Ponnuswami (1978) *In situ*, normal dose of the formulation (TOK E 25 emulsified concentrate at 91/ha) had no effect on the production of BGA in inoculum multiplication plots.

Ordram: see Molinate

Oxime-copper (fungicide) (bis(quinolin-8-olato) copper): Used at ? kg/ha.

Padhy (1985)

Oxydemeton-methyl, Metasystox R (insecticide) (S-2-ethylsulphinyethyl O,O-dimethyl phosphorothioate): used at 0.25–0.50 lbs/acre (0.3–0.6 kg/ha).

Mallison and Cannon (1984)

Panacide: see Dichlorophen

Paraquat (herbicide) (1,1'-dimethyl-4,4'-bipyridinium ion): destroys green plant tissue by contact action with some translocation. Used at 140–840 g ai/ha.

DaSilva et al. (1974)

DaSilva et al. (1975) *In vitro*, 20 ppm inhibited BNF by 9 of 9 strains of BGA.

Holst et al. (1982) *In vitro*, after 10 days, 0.1 ppm partially inhibited *Azolla* sp. growth on N<sub>2</sub>, 1 ppm caused a total inhibition.

Padhy (1985)

Parathion (insecticide) (O,O-diethyl O-4-nitrophenyl phosphorothioate): Used at 0.1–1 lbs/acre (0.11–1.1 kg/ha).

Ahmad and Venkataraman (1973) *In vitro*, no detrimental effect on *Aulosira fertilissima* at 1–2 ppm.

Padhy (1985)

Parathion-methyl (insecticide) (O,O-dimethyl O-4-nitrophenyl phosphorothioate): Non-systemic contact and stomach insecticide. Used at 0.25–2 lbs/acre (0.3–2.2 kg/ha).

Ahmad and Venkataraman (1973)

Padhy (1985)

PCB (?) (Polychlorinated biphenyls): used at ? kg/ha.

Zullei and Benecke (1978)

PCP (insecticide, fungicide, herbicide, algicide) (Pentachlorophenol): used as wood preservative and to control vector snails in Egypt at ? kg/ha).

Ishizawa and Matsuguchi (1966) in beakers with 70 g dry soil, 120 ppm had a negative effect on total algal counts in floodwater at 3 days after application, there was a recovery after 1 week, with 600 ppm, recovery was observed after 3 weeks, with 1,200 ppm recovery was observed at 46 days. 120 ppm inhibited N<sub>2</sub>-fixing BGA for one week but then increased their relative abundance, higher concentrations inhibited them for more than one month. This result was contradicted by a second experiment where PCP at field level was slightly inhibitory for BGA.

Mukerji (1972) *In situ*, algicidal against *Chara* and *Nitella* at 4–5 kg/ha but toxic to fish.

Padhy (1985)

Permethrin (insecticide) (3-phenoxybenzyl (1RS,3RS;1RS,3SR)-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate): Contact insecticide effective against a broad range of pests at 100–150 g ai/ha.

Padhy (1985)

Stratton (1980)

Stratton and Corke (1982)

PMA B: Used at ? kg/ha.

Padhy (1985)

Sharma and Gaur (1980) *In vitro*, tolerance was 0.05–0.3 ppm by 4 strains of *Nostoc* and 4 strains of *Aulosira fertilissima*.

Phorate, Thimet (insecticide) (O,O-diethyl S-ethylthiomethyl phosphorodithioate): Systemic and contact insecticide and acaricide used at 0.5–3 lbs/acre (0.33–5.5 kg/ha).

Bongale (1985) *In vitro*, 100 ppm had no significant effect on *Hapalosiphon* sp. and *Nostoc microscopium*.

Gangawane (1979) *In vitro* was not deleterious to *Westiellopsis* sp., *Aulosira* sp., *Tolypothrix* sp. and *Calothrix* sp. at concentration of 300 ppm but 1 ppm inhibited *Nostoc* sp.

Kaushik and Venkataraman (1983)

Padhy (1985)

Saha et al. (1982) *In vitro*, 0.5 and 1 ppm stimulated BNF and increased chlorophyll content in *Nostoc* sp. (2).

Saha et al. (1984) *In vitro*, 5 ppm had no effect on N accumulation by *Nostoc muscorum* in N-free liquid culture, 25 ppm was lethal. 1 ppm had no effect on *Nostoc piscinale* and 10 ppm caused 50 percent inhibition. Experiments with 10 g soil inoculated with BGA showed an increase in total soil N up to at least 25 ppm.

Sardespande and Goyal (1982) *In vitro*, 1 ppm had no or little effect on N accumulation by *Anabaena iyengarii*, *Hapalosiphon intricatus*, *Calothrix membranacea* and *Calothrix bharadwaja*. 50 percent inhibition values were observed between 5 and 20 ppm. 50 ppm was inhibitory but not lethal for all the strains.

Satapathy and Singh (1987) *In situ*, 0.15 kg ai/ha controlled *Azolla* sp. pests with no detrimental effect on the fern.

Sinha et al. (1986) 50 ppm was needed for use as molluscicide.

Srinivasan (1981) *In situ*, 3.9 kg/ha significantly increased the production of BGA in inoculum production plots.

Phosvel (?) (?):

Sharma and Gaur (1980) *In vitro*, tolerance was 100–150ppm by 4 strains of *Nostoc* sp. and 4 strains of *Aulosira fertilissima*.

Sharma and Gaur (1982)

Sharma (1984)

Picloram (herbicide) (4-amino-3,5,6-trichloropyridine-2-carboxylic acid): used at 0.3–3.3 kg ai/ha.

Arvik et al. (1971) *In situ* 0.28, 0.56, and 1.12 kg/ha of picloram caused no change in the composition of the algal flora over an 18-month period, regardless of dosage. *In vitro* it inhibited *Chlorella vulgaris*, *Cylindrospermum licheniforme* and *Chlorococcum* sp. at 50 ppm.

Padhy (1985)



Profluralin (herbicide) (N-(cyclopropylmethyl)-alpha,alpha, alpha-trifluoro-2,6-dinitro-N-propyl-p-toluidine): Soil-incorporated before planting at 0.75–1.5 kg ai/ha.

Hawxby et al. (1977) *In vitro*, concentrations up to 10 mol had no effect on *Lyngbia* and *Anabaena*, while 10 mol reduced *Chlorococcum* and *Chlorella* growth by 50 percent.

Mallison and Cannon (1984)

Prometone (herbicide) (2,4-bis(isopropylamino)-6-methoxy-1,3,5-triazine): non-selective herbicide used at 10–20 kg ai/ha on non crop areas.

Padhy (1985)

Prometryne (herbicide) (N,N'-di-isopropyl-6-methylthio-1, 3, 5-triazine-2, 4-diyl diamine): used either pre- or post-emergence at 1–1.5 kg ai/ha.

Addison and Bardsley (1968)

Hawxby et al. (1977) *In vitro*, 1 mol inhibited *Chlorella* and *Lyngbia* by 50 percent and 10 mol inhibited *Chlorella*, *Lyngbia*, *Chlorococcum* and *Anabaena* by 90–100 percent.

Propanil, Stam F-34 (herbicide) (3',4'-dichloropropionanilide): Contact herbicide recommended for post-emergence at 1–4 kg/ha.

Ahmad and Venkataraman (1973) [no detrimental effect on *Aulosira fertilissima* when used at the recommended dose.

El-Sawy et al. (1984) In pot, 12 kg/ha had some inhibitory effect on inoculated *Nostoc muscorum* and *Anabaena oryzae*.

Hamdi et al. (1970) *In vitro*, 0.18 ppm, 25 percent inhibition; 1.8 ppm, 45 percent inhibition; 18 ppm total inhibition on cultures of *Tolypothrix tenuis*.

Ibrahim (1972) *In vitro*, 1 ppm caused a partial inhibition on growth on *Tolypothrix tenuis* and *Calothrix brevissima*, complete inhibition was observed at 10 ppm.

Maule and Wright (1984) *In vitro*, EC50 values ranged from 0.09 ppm for *Chlorella pyrenoidosa* to 2.65 ppm for *Zygnema cylindricum*.

Maule and Wright (1984) *In vitro* experiment with 7 green algae and 6 BGA, EC50 values ranged from 0.1 to 2.65 ppm.

Padhy (1985)

Pandey (1985) *In vitro*, 0.5 to 20 ppm partially decreased growth and N<sub>2</sub> fixation by *Nostoc calcicola*, 30 ppm was lethal.

Pandey et al. (1984) *In vitro*, not mutagenic to *Nostoc calcicola*.

R.P. Singh et al. (1986) *In situ*, 1.5 kg/ha had no significant effect on the composition of algal populations studied by direct count.

Smith et al. (1977) *In situ*, control of BGA was not achieved with 3–6ppm.

Srinivasan and Ponnuswami (1978) *In situ*, single dose of the formulation (Stam F 30 applied at 10 ma) decreased the production of BGA in inoculum multiplication plots by about 15 percent.

Vaishampayan et al. (1978) *In vitro*, 1 ppm inhibited *Nostoc muscorum* by about 25 percent. 50 percent inhibition was observed at about 10 ppm.

Wright et al. (1977)

Propazine (herbicide) (6-chloro-N,N'-di-isopropyl-1,3,5-triazine-2,4-diylidiamine):

Pre-emergence herbicide used at 0.5–3.0 kg ai/ha.

Padhy (1985)

Venkataraman and Rajylakswami (1971) 17 strains could grow at > 100 ppm, 5 at 5 or 10 ppm, and 3 at 1 ppm.

Propham (herbicide) (isopropyl carbanilate): used at 2.3–5.0 kg ai/ha.

Padhy (1985)

Propoxur (insecticide) (2- isopropoxyphenyl methylcarbamate): used at 0.2–1 lbs/acre (0.22–1.1 kg/ha).

Padhy (1985)

Wurtsbaugh and Apperson (1978)

Quinalphos (insecticide) (O,O-diethyl O-quinoxalin-2-yl phosphorothioate): contact and stomach insecticide and acaricide used at 190–500 g ai/ha.

Padhy (1985)

Srinivasan (1981) *In situ*, 1.8 kg/ha significantly increased the production of BGA in inoculum production plots.

Subramanian (1982) *In situ* 0.25 ppm had no effect on 4 strains of *Anabaena*. 5 ppm caused a transitory inhibition for about 10–15 days then growth resumed. 25 ppm was lethal

Megharaj et al. (1988) *In vitro*, inhibited *Nostoc linckia* growth by 10 percent at 5 ppm, 30 percent at 10 ppm and 100 percent at 20 ppm.

Megharaj et al. (1989) *In vitro*, Quinalphos at 5 ppm inhibited by 90 percent the growth of *Scenedesmus bijugatus* measured after 20 d; 10 ppm caused total inhibition. 5 ppm had no significant effect on the growth of *Synechococcus elongatus*. 10 ppm caused an inhibition by 16 percent, and 25 ppm caused a total inhibition.

Quintozene, Brassicol (fungicide) (pentachloronitrobenzene): used for seed treatment of as soil disinfectant at 5–200 lbs/acre (5.5–220 kg/ha).

Gangawane (1980) *In vitro*, 500 and 1,000 ppm caused partial inhibition in growth of *Westiellopsis* sp., *Aulosira* sp., *Nostoc* sp., *Tolypothrix* sp. and *Calothrix* sp.; lower concentrations had no effect.

Gangawane et al. (1982) *In vitro*, 1 ppm was not inhibitory to *Nostoc* sp. and *Tolypothrix tenuis*.

Padhy (1985)

Ricetrine (algicide) (organic copper chelate): Used at 15 lbs/acre in ricefields to control algae (16 kg/ha).

Dunigan and Hill (1978)

Dunigan et al. (1979) *In situ*, 2 ppm Cu prevented algal growth if used when no algae were blooming.

Roccal (algicide) (?):

Das 1976

Rogor: see Dimethoate

Rovral: see Iprodione

Ruberon (?) (mercuric ethyl phosphate):

Ishizawa and Matsuguchi (1966) In beakers experiments, had no significant effect at field dose on algal populations.

Saturn: see Simetryne

Sencor: see Metribuzin

Sevin: see Carbaryl

Silvex: see 2,4,5,-TP

Simazine (herbicide, algicide) (6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diylidamine): used at 1–4 lbs/acre (1.1–4.5 kg/ha).

Das (1976)

Holst et al. (1982) *In vitro*, after 10 days, 10 ppm had no effect on *Azolla* sp. growth on N<sub>2</sub>.

Goldsborough & Robinson (1986) *In situ* trials in swamp enclosures showed no reduction in total algal biovolume at 0.1 ppm simazine, with increasing inhibition (to 98 percent) at 1.0 and 5.0 ppm.

Kumar and Singh (1981) *In vitro* at 10 days of growth, 4–6 ppm caused partial growth inhibition < 20 percent with *Anabaena doliolum*; 8 ppm caused a 95 percent inhibition. 1–4 ppm caused partial growth inhibition with *Nostoc linckia*; 50 percent inhibition was at 2 ppm

Mallison and Cannon (1984)

Mehta and Hawxby (1979) *In vitro* 2 ppm caused a 50 percent reduction in growth in *Anacystis nidulans*

Padhy (1985)

Patnaik and Ramachandran (1976) *In situ*, 0.3–0.5 ppm simazine can efficiently control deleterious *Microcystis* blooms in fish ponds.

Pillay and Tchan (1972)

Tomaselli et al. (1987) *In situ* repeated use of simazine (4 kg/ha) affected more severely heterocystous BGA and strongly reduced species diversity.

Simetryne, Saturn (herbicide) (N,N'-diethyl-6-methylthio-1,3,5-triazine-2,4-diyl di amine): used at 4 kg/ha

Mishra and Pandey (1989) *In vitro*, 6–8 ppm Saturn was lethal on *Nostoc linckia*, *Nostoc calcicola*, *Nostoc* sp. and *Anabaena doliolum*.

Padhy (1985)

Srinivasan and Ponnuswami (1978) *In situ*, double dose of the formulation (Saturn 50 percent 16 l/ha) had no effect on the production of BGA in inoculum multiplication plots.

Stam F-34: see Propanil

TCA (herbicide) (trichloroacetic acid): applied at pre-emergence at 7–15 kg ai/ha.

Padhy (1985)

Temephos (insecticide) (O,O,O',O'-tetramethyl O,O'-thiodi-p-phenylene bis (phosphorothioate): used at 0.25–1 lbs/acre (0.3–1.1 kg/ha).

Padhy (1985)

Wurtsbaugh and Apperson (1978)

Terbuthylazine (herbicide) (N-tert-butyl-6-chloro-N'-ethyl-1,3,5-triazine-2,4-diyl diamine): Controls a wide range of weeds, is absorbed mainly by plant roots, and is used at 1.2–1.8 kg ai/ha.

Hawxby et al. (1977) *In vitro*, 0.1 mol inhibited *Chlorella* and *Lyngbia* by about 50 percent; 10 mol had a marked inhibitory effect on *Lyngbia* and *Anabaena*, *Chlorococcum* and *Chlorella*.

Terbutryne (herbicide, algicide) (N-tert-butyl-N'-ethyl-6-methylthio- 1,3,5-triazine-2,4-diylidiamine): Selective herbicide for pre-emergence used at 1–2 kg ai/ha.

Goldsborough & Robinson (1986) *In situ* trials in enclosures showed > 98 percent decrease of total algal biovolume at 0.01, 0.1 and 1.0 ppm terbutryn. Muirhead et al. (1989)

Wegener et al. (1985) In experiments with 23 g of non submerged soil, terbutryne at recommended doses for field application inhibited algal growth and BNF for about two months.

Thimet: see Phorate

Thiophanate (fungicide) (diethyl 4,4'-(o-phenylene)bis(3-thioallophanate): used at ? kg/ha.

Gangawane and Kulkarni (1979)

Thiodicarb (insecticide) (?)

Sinha et al. (1986) *In situ*, 1 ppm reduced snail populations by 50 percent without detrimental effect on algae.

Thiram (Fungicide) (tetramethylthiuram disulphide): used at 1–6 lbdacre (1.1–6.6 kg/ha).

Cameron and Julian (1984)

Gangawane et al. (1982) *In vitro*, 1 ppm inhibited *Nostoc* sp. but was not inhibitory to *Tolypothrix* tenuis.

Gangawane and Kulkarni (1979) *In vitro*, 1 ppm inhibited *Westiellopsis* sp., *Aulosira* sp. and *Calothrix* sp., concentrations lower than 1,000 ppm had no effect on *Nostoc* sp., concentrations lower than 300 ppm had no effect on *Tolypothrix* sp.

Hotter et al. (1979) The concentration causing a 50 percent reduction of photoautotrophic growth *in vitro* was 50 ppm for *Aphanocapsa* 6714, 100 ppm for *Aphanocapsa* 6308, 50 ppm for *Anabaena* variabilis, and 100 ppm for *Nostoc* sp.

Padhy (1985)

TOK: see Nitrophen

Tolkan: see Dinoseb

Topsin-M: see Thiophanate

Trifluralin (herbicide) (alpha,alpha,alpha-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine): Pre-emergence herbicide used at 0.5–1.0 kg ai/ha.

Hamdi et al. (1970) *In vitro*, 0.25 ppm, 25 percent inhibition; 2.5 ppm, 45 percent inhibition; 25 ppm 80 percent inhibition on cultures of *Tolypothrix tenuis*.

Holst et al. (1982) *In vitro*, after 10 days, 10 ppm did not inhibit *Azolla* sp. growth on N<sub>2</sub>.

Ibrahim (1972) [ 1 ppm caused a partial inhibition on growth on *Tolypothrix tenuis* and *Calothrix brevissima*, complete inhibition was observed at 10 ppm for *Tolypothrix* and 100 ppm for *Calothrix*.

Padhy (1985)

Thimet: see Phorate

Vapam: see Metham

Weedone: see 2,4-D

Zineb (fungicide) (zinc ethylenebis [dithiocarbamate]): Used at 3–15 lbs/acre (3.3–16 kg/ha).

Das (1976)

Gangawane et al. (1982) *In vitro*, 1 ppm was not inhibitory to *Nostoc* sp. and 10 ppm was not inhibitory to *Tolypothrix tenuis*.

Padhy (1985)

Ziram (fungicide) (zinc dimethyldithiocarbamate): Used at 3–15 lbs/acre (3.3–15 kg/ha).

Padhy (1985)

### Part 3. Tabulated Values of the Recommended Doses of Pesticides

Table D.1. Recommended Doses of Fungicides Tested *in vitro* or *in vivo* on Algae Recorded in Ricefields

| <i>Fungicides</i>            | <i>Recommended Dose (kg ai/ha)</i> |                | <i>Mean</i> |
|------------------------------|------------------------------------|----------------|-------------|
|                              | <i>Minimum</i>                     | <i>Maximum</i> |             |
| Benomyl                      | 0.2                                | 0.5            | 0.3         |
| Captafol                     | 0.3                                | 2.0            | 1.1         |
| Carbendazim                  | 1.0                                | 1.0            | 1.0         |
| Carboxin                     | 0.4                                | 0.8            | 0.6         |
| Copper oxychloride           | 2.2                                | 5.5            | 3.9         |
| Copper sulphate <sup>a</sup> | 1.0                                | 2.6            | 1.8         |
| Dichlone                     | 0.3                                | 0.6            | 0.5         |
| Ethirimol                    | 0.7                                | 1.1            | 0.9         |
| Fentin acetate <sup>a</sup>  | 0.2                                | 0.3            | 0.2         |
| Fentin hydroxide             | 0.3                                | 0.4            | 0.3         |
| Ferbam                       | 1.1                                | 16.0           | 8.6         |
| Folpet                       | 2.2                                | 11.0           | 6.6         |
| Fytolan                      | 2.2                                | 5.5            | 3.9         |
| Iprodione                    | 0.5                                | 1.0            | 0.8         |
| Mancozeb <sup>a</sup>        | 1.4                                | 1.9            | 1.7         |
| Quintozene                   | 5.0                                | 200.0          | 103.0       |
| Thiram                       | 1.1                                | 6.6            | 3.9         |
| Zineb                        | 3.3                                | 16.0           | 9.7         |
| Ziram                        | 3.3                                | 15.0           | 9.2         |
| Minimum                      | 0.2                                | 0.3            | 0.2         |
| Maximum                      | 5.0                                | 200.0          | 102.5       |
| Median                       | 1.0                                | 2.0            | 1.7         |
| Average                      | 1.4                                | 15.1           | 8.3         |
| Standard deviation           | 1.3                                | 45.1           | 23.0        |

a. Also used as algicide.

Table D.2. Recommended Doses of Herbicides Tested *in vitro* or *in vivo* on Algae Occuring in Ricefields

| <i>Herbicides</i> | <i>Recommended Dose (kg ai/ha)</i> |                |             |
|-------------------|------------------------------------|----------------|-------------|
|                   | <i>Minimum</i>                     | <i>Maximum</i> | <i>Mean</i> |
| 2,4-D             | 0.3                                | 2.3            | 1.3         |
| 2,4,5-T           | 1.1                                | 13.5           | 7.3         |
| 2,4,5-TP          | 1.1                                | 4.4            | 2.8         |
| Alachlor          | 1.7                                | 4.5            | 3.1         |
| Ametryne          | 1.0                                | 9.0            | 5.0         |
| Amitrole          | 1.1                                | 22.4           | 11.8        |
| Atrazine          | 0.6                                | 5.6            | 3.1         |
| Barban            | 0.4                                | 0.6            | 0.5         |
| Ben(z)thiocarb    | 3.0                                | 6.0            | 4.5         |
| Bromacil          | 1.6                                | 3.2            | 2.4         |
| Butachlor         | 1.0                                | 4.5            | 2.8         |
| Chloramben        | 2.2                                | 4.5            | 3.4         |
| Chloridazon       | 1.6                                | 3.3            | 2.5         |
| Chlortoluron      | 1.5                                | 3.0            | 2.3         |
| Chlorpropham      | 2.2                                | 9.0            | 5.6         |
| Chlortalonil      | 1.1                                | 2.2            | 1.7         |
| Cyanazine         | 1.0                                | 3.0            | 2.0         |
| Dalapon           | 1.0                                | 22.0           | 11.5        |
| Dicamba           | 0.1                                | 11.0           | 5.6         |
| Dinoseb           | 2.0                                | 4.0            | 3.0         |
| Diphenamid        | 4.0                                | 6.0            | 5.0         |
| Diquat            | 1.0                                | 2.0            | 1.5         |
| Diuron            | 0.6                                | 4.8            | 2.7         |
| EPTC              | 3.0                                | 6.0            | 4.5         |
| Fluchloralin      | 0.5                                | 1.0            | 0.8         |
| Fluometuron       | 1.0                                | 1.5            | 1.3         |
| Fluorodifen       | 3.0                                | 4.0            | 3.5         |
| Glyphosate        | 0.3                                | 2.2            | 1.3         |
| Linuron           | 0.6                                | 3.4            | 2.0         |
| MCPA              | 0.3                                | 2.3            | 1.3         |
| MCPB              | 1.7                                | 3.4            | 2.6         |
| Mecoprop          | 1.5                                | 2.7            | 2.1         |
| Metolachlore      | 1.0                                | 2.5            | 1.8         |
| Metribuzin        | 0.4                                | 1.1            | 0.8         |
| Molinate          | 2.0                                | 4.0            | 3.0         |
| Monuron           | 10.0                               | 20.0           | 15.0        |
| Naptalam          | 2.0                                | 5.5            | 3.8         |
| Neburon           | 2.0                                | 3.0            | 2.5         |



Table D.2. (Continued)

| <i>Herbicides</i>       | <i>Recommended Dose (kg ai/ha)</i> |                |             |
|-------------------------|------------------------------------|----------------|-------------|
|                         | <i>Minimum</i>                     | <i>Maximum</i> | <i>Mean</i> |
| Nitrofen                | 2.0                                | 2.0            | 2.0         |
| Paraquat                | 0.1                                | 0.8            | 0.5         |
| Picloram                | 0.3                                | 3.3            | 1.8         |
| Profluralin             | 0.8                                | 1.5            | 1.1         |
| Prometone               | 10.0                               | 20.0           | 15.0        |
| Prometryne              | 1.0                                | 1.5            | 1.3         |
| Propanil                | 1.0                                | 4.0            | 2.5         |
| Propazine               | 0.5                                | 3.0            | 1.8         |
| Propham                 | 2.3                                | 5.0            | 3.7         |
| Ricetrine               | 1.0                                | 16.0           | 8.5         |
| Simazine <sup>a</sup>   | 1.1                                | 4.5            | 2.8         |
| Simetryne               | 1.1                                | 4.5            | 2.8         |
| TCA                     | 7.0                                | 15.0           | 11.0        |
| Terbuthylazine          | 1.2                                | 1.8            | 1.5         |
| Terbutryne <sup>a</sup> | 1.0                                | 2.0            | 1.5         |
| Trifluralin             | 0.5                                | 1.0            | 0.8         |
| Minimum                 | 0.1                                | 0.6            | 0.5         |
| Maximum                 | 10.0                               | 22.4           | 15.0        |
| Median                  | 1.1                                | 3.7            | 2.5         |
| Average                 | 1.7                                | 5.5            | 3.6         |
| Standard deviation      | 2.0                                | 5.5            | 3.4         |

a. Also used as algicide.

Table D.3. Recommended Doses of Insecticides Tested *in vitro* or *in vivo* on Algae Occurring in Ricefields

| <i>Insecticides</i> | <i>Recommended Dose (kg ai/ha)</i> |                |             |
|---------------------|------------------------------------|----------------|-------------|
|                     | <i>Minimum</i>                     | <i>Maximum</i> | <i>Mean</i> |
| Aldicarb            | 0.6                                | 11.2           | 5.9         |
| Aldrin              | 0.5                                | 5.0            | 2.8         |
| Carbaryl            | 0.3                                | 2.0            | 1.1         |
| Carbofuran          | 0.5                                | 4.0            | 2.3         |
| DDT                 | 1.1                                | 2.2            | 1.7         |
| Diazinon            | 0.3                                | 2.2            | 1.3         |
| Dicofol             | 0.6                                | 4.5            | 2.5         |
| Diiflubenzuron      | 0.0                                | 0.2            | 0.1         |
| Dimethoate          | 0.3                                | 0.7            | 0.5         |
| Endosulfan          | 0.2                                | 4.4            | 2.3         |
| Endrin              | 0.2                                | 0.5            | 0.4         |
| Gamma HCH           | 0.3                                | 4.4            | 2.4         |
| Malathion           | 0.6                                | 3.3            | 1.9         |
| Methoxychlor        | 0.3                                | 0.6            | 0.5         |
| Monocrotophos       | 0.6                                | 1.1            | 0.8         |
| Oxydemeton-methyl   | 0.3                                | 0.6            | 0.5         |
| Parathion           | 0.1                                | 1.1            | 0.6         |
| Parathion-methyl    | 0.3                                | 2.2            | 1.3         |
| Permethrin          | 0.1                                | 0.2            | 0.1         |
| Phorate             | 0.3                                | 5.5            | 2.9         |
| Ropoxur             | 0.2                                | 1.1            | 0.7         |
| Quinalphos          | 0.2                                | 0.5            | 0.4         |
| Temephos            | 0.3                                | 1.1            | 0.7         |
| Minimum             | 0.0                                | 0.2            | 0.1         |
| Maximum             | 1.1                                | 11.2           | 5.9         |
| Median              | 0.3                                | 2.0            | 1.1         |
| Average             | 0.4                                | 2.5            | 1.4         |
| Standard deviation  | 0.2                                | 2.5            | 1.3         |

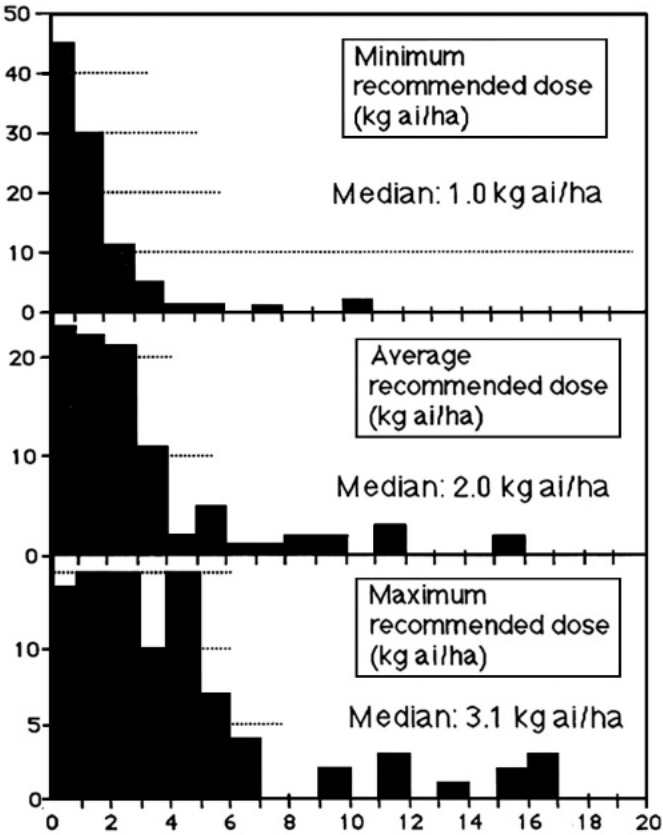


Figure D.3. Histograms of Minimum, Maximum, and Average Recommended Doses of Pesticides Tested *in vitro* or *in vivo* on Algae Occuring in Ricefields

# APPENDIX E

## ANNOTATED BIBLIOGRAPHY ON THE EFFECTS OF PESTICIDES ON NONPHOTOTROPHIC MICROORGANISMS OF RICEFIELDS

P.A. Roger

This annotated bibliography presenting ninety-five references dealing with the effects of pesticide on ricefield microflora. Papers selected include:

- All papers dealing with the effects of pesticides on nonphototrophic microorganisms and microbial activities and reporting studies in ricefields, with ricefield soil, or with strains isolated from ricefields or known to be present in ricefields;
- Few papers of interest for methodological aspects or presenting data useful for comparison; and
- Bibliographic reviews including references on wetland soils.

The following code is used:

- (NS) (No summary) The original paper has no summary.  
(NC) (Not consulted) The paper was not available and is cited from another paper.  
Abstract: The document cited is only an abstract, not a full paper.  
Summary: The summary or abstract is included in the original paper.  
Notes: Short summary or comments by the author of this compilation.

Akhtar, S., Solangi, H., Baig, M.M.H. (1986) Effect of DDT on soil microorganisms isolated from Punjab paddy field. *Pakistan J. Sci. Ind. Res.* 29(6): 444–447.

*Summary:* Comparison between the application of DDT technical 70 percent and DDT formulation 50 percent WP at recommended dose (1 kg/ha) indicates a similar level of retardation of microbes, showing only 20–30 percent growth as compared to control. Tolerance study indicate that *B. apairius* and *S. epidermis* can stand formulations up to 200 times higher than the normal field application rate, whereas, *B. megaterium*, *B. subtilis*, and *B. circulans* showed minimum tolerance to DDT's normal field application rate.

*Notes:* Inoculation of soil suspension dilution on agarized medium in petri dishes. At the recommended dose (1 kg ai/ha) DDT had no significant effect on five strains and reduced growth of three probably by more than 50 percent.

Anderson, J.P.E., Armstrong, R.A., Smith, S.N. (1981) Methods to evaluate pesticide damage to the biomass of the soil microflora. *Soil Biol. Biochem.* 13(2): 149–154.

*Summary:* Respiratory methods to estimate the amount of C in the soil microbial biomass and the relative contributions of procaryotes and eucaryotes to the biomass were used to evaluate the influence of pesticides on the soil microflora. Experiments were conducted with 5 and 50 µg/g of three fungicides, captan, thiram and verdasan. At 5 µg/g they caused significant decreases (40 percent) in the biomass; the organomercury fungicide verdasan also caused a shift from fungal to bacterial dominance. Within eight days, biomass in captan- and thiram-amended soils had recovered to that of the controls. Although the fungal to bacterial balance was restored in verdasan-amended soils, biomass recovery was not complete. At 50 µg/g the fungicides caused long-term decreases in the biomass and altered the relative proportions of the bacterial and fungal populations. Verdasan had the greatest effect on soil microbial biomass and composition.

*Notes:* Deals with upland soil. Respirometric methods useful in upland soils are much less suitable for submerged soil where both methane and CO<sub>2</sub> are produced.

Anderson, J.R. (1978) Pesticide effect on non-target soil microorganisms. Pages 313–533 in Hill, I.R., Wright, S.J.I., (eds.), *Pesticide microbiology*. Academic Press, London. (NS)

*Notes:* This review deals mostly with upland soils. It covers work published between 1965 and 1976. It includes more than 500 references and tabulated data of pesticide effects over 118 pages.

Among a total of 1,016 records of effects, only 11 deal with rice soils; 920 records deal with herbicides, 20 with fungicides, and 76 with insecticides.

Azad, M.I., Khan, A.A. (1968) Studies upon the reduction of nitrogen losses through denitrification from paddy soil by the application of pesticides. *West Pakistan J. Agr. Res.* 6(4): 128–133.

*Summary:* The studies were carried out in the laboratory of the Chemical Section, Agricultural Research Institute, Tarnab, Peshawar under controlled conditions. The data reveal that both the chemicals proved themselves partially inhibitive for denitrifiers. The detrimental effect of the chemicals on denitrifiers increased with the increase in the concentration in application rates and decreased with the increase in duration. The results suggest that a constant application of both the chemicals (Endrin and Dimecron) at the rate of 25 ppm at fortnight intervals to paddy soil will reduce the nitrogen losses caused by denitrification process to a great extent.

*Notes:* Experiment with 100 g of soil in flasks

Baruah, M., Mishra, R.R. (1986) Effect of herbicides butachlor, 2,4-D and oxyfluorfen on enzyme activities and CO<sub>2</sub> evolution in submerged paddy field soil. *Plant Soil* 96(2): 287–291.

*Summary:* Effects of three herbicides 2,4-D, butachlor and oxyfluorfen on activities of dehydrogenase, urease and carbon dioxide evolution from paddy field soil were measured on weekly intervals. Dehydrogenase activity was significantly stimulated on application of herbicides. The herbicides did not affect the urease activity and the activity remained almost unchanged. The carbon dioxide output was higher in herbicide treated soil.

Brungs, W.A., Mount, D.I. (1978) Introduction to a discussion of the use of aquatic toxicity tests for evaluation of the effects of toxic substances. Pages 15–26 in Cairns, J. Jr., Dickson, K.L., Maki, A.W. (eds.), *Estimating the hazard of chemical substances to aquatic life*, ASTM STP 657, American Society for Testing and Materials.

*Summary:* A variety of classes of aquatic toxicity tests are presented and discussed in relation to their ability to provide useful estimates of the environmental effects of chemicals or discharges. These classes of tests can be judged and compared numerically by several standards: ability to permit extrapolation to meaningful effect; ease and cost of conducting tests; applicability to response to a wide variety of chemicals; availability of documented detailed procedures; ecological importance and persistence of effect; and scientific and legal defensibility

of the procedure. No single class of tests can be expected to be clearly superior to all others, indicating the need for a variety of testing at successive tiers of intensity of study.

Chao, C.C. (1983) Effects of insecticides on the population of soil microorganisms and crop growth. *J. Agric. Assoc. China* 124: 89–98.

*Summary:* In this study, endeavors were made to investigate the effects of insecticides, Methomyl and Monocrotophos on the growth and function of various soil microorganisms and plants in pot experiments. They were applied individually in the pots at the concentrations ranging from 1, 5, 10, to 100 times of the field recommended rate. The microorganisms studied were the urea-hydrolyzing organisms, the heterotrophic nitrogen fixers, the nitrifiers, some heterotrophic bacteria and fungi. The two plants employed were corn and rice for upland and paddy-soil experiments respectively. The toxicity of Methomyl to the nitrifiers manifested in four days and to the heterotrophic bacteria in two weeks. However, it promoted the growth of the urea-hydrolyzing organisms and fungi two weeks after the addition of pesticide. The chemical had no effect on the nitrogen fixer, *Azotobacter* sp., but for corn it was a potent poison, especially as the dose reached 100 times of the normal rate. It did not stunt the growth of plant, but it lowered the kernel yield. To the soil microbes and rice plant, Monocrotophos was rather mild. Its use, even at the dosage 100 times above normal rate, caused rice no ill consequences. The growth of the heterotrophic bacteria and *Azotobacter* sp. was hampered by the chemical in the first two weeks of spraying, but afterwards they soon recovered. Monocrotophos was not toxic to fungi, and was even stimulatory to a minor degree for the urea-hydrolyzing organisms.

Charyulu, P.B.B.N., Ramaknshna, C., Rao, V.R. (1980) Effect of 2-aminobenzimidazole on nitrogen fixers from flooded soil and their nitrogenase activity. *Bull. Environ. Contam. Toxicol.* 25: 482–486. (NS)

*Notes:* 2-aminobenzimidazole is a degradation product of Benomyl. Concentration of 10, 20, and 100 ppm had either no effect or positive effects on populations of  $N_2$ -fixing microorganisms. At all concentrations, 2-aminobenzimidazole retarded the drop in Eh observed in soil after submersion.

Chen, Y.L. (1980) Degradation of butachlor in paddy fields. Pages 121–142 in *FFTC Book Series No. 20: Weeds and weed control in Asia*. Food and Fertilizer Technology Center, Taiwan. (NS)

*Notes:* Extensive experimental survey of all pathways of butachlor disparition from ricefields. Includes data on its effect on nitrification at different temperatures

and pH. At 30°C and pH 6.8, 6 ppm butachlor simulated nitrification, soil respiration, had no significant effect on populations of fungi and actinomycetes but possibly increased total populations of bacteria for about two weeks.

Chendrayan, K., Sethunathan, N. (1980) Effect of HCH, carbaryl and atrazine on the dehydrogenase activity in a flooded soil. *Bull. Environ. Contam. Toxicol.* 24: 379–382.

*Notes:* Pesticides used at 1 ppm (value close to the recommended dose) had no effect on dehydrogenase activity of the soil and its redox potential.

Chopra, P., Magu, S.P. (1986) Respiration as influenced by urea herbicides in soil amended with compost. *Int. J. Trop. Agric.* 4(2): 137–142.

*Summary:* Under laboratory conditions, soil respiration was inhibited by tribunil (0.5 to 5 ppm) and isoproturon (0.35 to 3.50 ppm) at fifteen and thirty days of the incubation. The incorporation of 0.5 percent w/w paddy straw compost with different doses of tribunil mitigated the toxicity at thirty days. However, in case of isoproturon, the amelioration was observed only with 0.35 ppm. Under wheat crop, isoproturon reduced carbon dioxide evolution at ten weeks of plant growth. However, the toxicity of the herbicide was reduced in the presence of paddy straw compost. At sixteen weeks (harvesting stage) soil respiration was observed to increase significantly in all doses of both isoproturon (0.35, 0.70, 1.40 ppm) and tribunil (1.0, 2.0, 5.0 ppm) treated with compost.

*Notes:* Pot experiment with non submerged soil planted with wheat.

Chowdhury, A.K., Mukhopadhyay, A.K., Mukhopadhyay, S. (1972) Influence of certain herbicides on the fungal populations in soils. *Indian Phytopath.* 25: 188-194.

*Notes:* Cited in Anderson (1978). Propanil at 2, 3, and 4 kg/ha, Nitrofen at 2, 4, and 6 kg/ha, and Prometryne at 0.25–1.0 kg/ha caused a transitory decrease of populations of *Aspergillus* and *Fusarium*.

Cooper, S.L., Wingfield, G.I., Lawley, R., Greaves, M.P. (1978) Miniaturized methods for testing the toxicity of pesticides to microorganisms. *Weed Res.* 18: 105–107.

*Summary:* A miniaturized method of determining the toxicity of pesticides to a large number of soil microorganisms is described. Bacteria, actinomycetes, yeasts, fungi, and algae can be used as test organisms. A modification of the methods allows determination of minimum inhibitory concentration of



pesticides to specific microorganisms. Some results obtained with herbicides are presented.

De, B.K., Mukhopadhyay, S. (1971) Effect of MCPA and Stam F-34 on the Occurrence of some nutritional groups of bacteria in the ricefields of west Bengal. *Int. Rice Commn. Newsl.* 220: 35–39.

*Notes:* Cited in Anderson, J.R. (1978). Study with a West Bengal ricefield soil. Propanil at 3.14 and 5.3 kg/ha decreased populations of nitrifiers. At 10.5 kg/ha it caused a large decrease in denitrifiers and denitrification. At 10.2 and 17.1 kg/ha it decreased cellulolytic populations. MCPA at 2.25 kg/ha caused a large decrease in denitrifiers and denitrification.

Endo, T., Kusaka, T., Tan, N., Sakai, M. (1982a) Effect of the insecticide cartap hydrochloride on soil enzyme activities, respiration and nitrification. *J. Pest. Sci.* 7: 101–110.

*Summary:* The effect of cartap hydrochloride (cartap-HCl; Padan) on soil enzyme activities, respiration and nitrification were examined for thirty or sixty days in laboratory-conditioned upland and flooded soils. Cellulase and saccharase activities were not influenced, even by 1,000 ppm treatment in either conditions. Phosphatase activity in 1,000 ppm treatment decreased but the recovered. Protease activity under flooded conditions was depressed by 1,000 ppm treatment during the first fifteen days, but became higher than in the untreated soil after thirty days. This activity under upland conditions decreased in the 100 and 1,000 ppm treatments over the entire sixty-day period. Oxygen uptake was retarded by 1,000 ppm treatment during thirty days but it subsequently recovered. In the soils treated with cartap HCl at 100 and 1,000 ppm,  $\text{NH}_4\text{-N}$  accumulated but  $\text{NO}_2\text{-N}$  and  $\text{NH}_3\text{-N}$  diminished. These findings suggest that nitrifying organisms were affected by high concentrations of Cartap HCl. All of the four enzymes activities, respiration and nitrification showed very little changes at normal application rates (10 ppm) of the chemical in the soil under upland and flooded conditions.

Endo, T., Kusaka, T., Tan, N., Sakai, M. (1982b) Effect of the insecticide cartap hydrochloride on soil microflora. *J. Pest. Sci.* 7: 1–7.

*Summary:* The effect of cartap hydrochloride (cartap-HCl; Padan) on soil microflora was examined under laboratory conditions. Cartap-HCl at 10 ppm (a normal application) and 100 pm treatments had no appreciable influence on the populations of fungi, actinomycetes, aerobic and anaerobic bacteria under upland and flooded conditions. However, the populations of the microorganisms

were decreased by treatment at 1,000 ppm of the chemical under both conditions. Fungal and actinomycete populations were less in soil treated at 1,000 ppm than in untreated soil during sixty days. The numbers of aerobic and anaerobic bacteria at 1,000 ppm of the chemical under both conditions decreased for the first three and fifteen days, respectively, but subsequently recovered. Fungal flora was not affected by 10 and 100 ppm treatments under either condition, but the fungal composition was changed by 1,000 ppm treatment under upland conditions, namely, the rate of *Penicillium* sp. in total fungi decreased, while those of *Trichoderma* sp. and *Fusarium* sp. increased. Under flooded conditions, even treatment at 1,000 ppm made little or no remarkable change on the fungal flora.

*Notes:* Under flooded conditions, at recommended dose of 10 ppm and at 100 ppm had no effect on fungi, actinomycetes, aerobic bacteria, and anaerobic bacteria.

Fox, J.L. (1983) Soil microbes pose problems for pesticides. *Science* 221: 1029–1031. (NS)

*Notes:* Short review on the problem of pesticide inactivation by adaptive soil microflora.

Furusaka, C. (1978) Dynamic aspects of bacterial flora in connection with behaviors of pentachlorophenol scattered on paddy field—under consideration of methodology. *J. Pest. Sci. (Japan)* 3: 499–509. (In Japanese)

*Summary:* By citing an example of PCP applied in the paddy field, problems were discussed in relation to methodology applicable to the research on the transition of microflorae in the environment. The further problem seems to be how to generalize findings of the studies made both from micro and macroscopic viewpoint into a universal law.

Goring, C.A.I., Laskowski, D.A. (1982) The effects of pesticides on nitrogen transformations in soils. Pages 689–720 in *Nitrogen in agricultural soils*, American Society of Agronomy Madison, Wis., USA. (NS)

*Notes:* A review with tabulated data on pesticide effects on organisms and activity. Most of the information is on upland soils. 165 references including five references on ricefields.

Gowda, T.K.S., Rao, V.R., Sethunathan, N. (1977) Heterotrophic nitrification in the simulated oxidized zone of a flooded soil amended with benomyl. *Soil Sci.* 123(3): 171–175.

*Summary:* In a study of benomyl-soil microflora interactions in a simulated oxidized zone of a flooded soil, application of 5,000 ppm benomyl together with ammonium sulphate increased bacterial numbers in an alluvial soil. Nitrite was produced from ammonium in benomyl-amended soil, though in small quantities which disappears later. Oxidation of nitrite to nitrate was not evident. No nitrite was detected in unamended soil. Also, the predominant bacterium isolated from benomyl-amended soil and identified as *Pseudomonas* sp., oxidized ammonium to nitrite in a medium containing glucose. Moreover, oxidation of ammonium to nitrite occurred in benomyl-amended soil as well as in bacterial cultures even in the presence of N-Serve or AM at concentrations known to inhibit autotrophic nitrification. At the same time, benomyl, even at 100 ppm inhibited nitrification by *Nitrosomonas* and *Nitrobacter*.

*Notes:* The benomyl concentration used in this experiment (5,000 ppm) is much higher than the recommended dose (less than 1 kg ai/ha).

Greaves, M.P., Cooper, S.L., Davies, H.A., Marsh, J.A.P., Wingfield, G. (1978) *Methods of analysis for determining the effects of herbicides on soil micro-organisms and their activities*. Technical Report No. 45. Agricultural Research Council Weed Research Organization, Bagbroke Hill, Yarnton, Oxford, OX5 1PF, UK. 56 pp. (NS)

*Notes:* Soil sampling, calculations to quantify pesticide use and most classical methods of soil microbiology are listed and described.

Ishizawa, S., Matsuguchi, T. (1966) Effects of pesticides and herbicides upon microorganisms in soil and water under waterlogged condition. *Bull. Nat. Inst. Agr. Sci. Ser. B* 16: 1–90. (NC)

Jayachandran, and Chandramohan, N. (1977) Influence of insecticides on the phyllosphere and rhizosphere of rice crop. *Riso* 26(4): 323–330.

*Summary:* Although all the insecticides tested were inhibitory to the phyllosphere microflora, contact insecticides exerted least inhibitory effect compared to systemic insecticide both on the twenty-fifth and fifty-fifth day of sampling. The insecticides applied to the rice plants altered the composition of the leaf exudates and there existed no relation between the leachate composition and phyllosphere microflora. On the twenty-fifth day although all the insecticides excepting counter and cytolane stimulated the rhizosphere microflora, on the fifty-fifth day the contact insecticides alone were stimulatory. No correlation could be observed between the rhizosphere population and enzyme activity both on the twenty-fifth and fifty-fifth day of sampling.

Jena, P.K., Rajaramamohan Rao, V. (1987) Nitrogen fixation as influenced by pesticides and rice straw in paddy soils. *J. Agric. Sci. (G.B.)* 108(3): 635–638.

*Summary:* The effect of three herbicides and an insecticide combination on nitrogen fixation in three paddy soils was investigated in a laboratory incubation study. The influence of pesticide combination on  $N_2$  fixation was evaluated in the presence and absence of rice straw under flooded and non-flooded conditions. In a non-flooded alluvial soil single or combined application of butachlor and carbofuran significantly stimulated  $N_2$  fixation. There was no effect on  $N_2$  fixation when thiobencarb was applied alone; but with thiobencarb in combination with carbofuran higher  $N_2$  fixation occurred. Both oxadiazon and thiobencarb had no effect on  $N_2$  fixation under flooded conditions, but in combination with carbofuran and  $N_2$  fixation was high. In acid sulphate saline Pokkali soil, rice straw application stimulated  $N_2$  fixation; the stimulatory effect of carbofuran either alone or in combination became more pronounced under flooded conditions.  $N_2$  fixation was low in a laterite Sukinda soil and the effect of pesticides was not changed by rice straw amendment. A uniform stimulation of  $N_2$  fixation occurred in soils when carbofuran was applied either singly or in combination with other herbicides tested. Results indicate that the effect of pesticides on  $N_2$  fixation varied with the rice straw application and water regime.

Kai, H., Kamata, M., Kawagushi, S., Kanayama, H. (1986) Effects of herbicide applications on microbial ecosystem and fertility of paddy soil. I. Seasonal changes of microflora affected by repeated applications of herbicides in paddy soil. *Jap. J. Soil Sci. Plant Nutr.* 57(6): 535–543. (In Japanese) (NS)

Kandasamy, D., Marimuthu, T., Rajukkannu, K., Raghuraj, R., Oblisami, G., Krishnamoorthy, K.K., Subrahmaniam, T.R. (1975) A study on the relationship between the dissipation of insecticides and rhizosphere microflora of paddy. *Madras Agric. J.* 62(4): 203–207.

*Summary:* A study on the interrelationship between the dissipation of two granular insecticides and different microbial populations in the rhizosphere soil of paddy crop indicated a positive correlation between the residues of phorate and actinomycete and *Azotobacter* populations. However, no such definite relationship could be recorded with carbofuran and various groups of microflora.

Kuthubutheen, A.J. (1980) Effect of pesticides on leaf and seed surface fungi of rice. Pages 1,021–1,028 in Furtado, J.I. (ed.) *Tropical Ecology and Development. Proceedings of the fifth International Symposium of Tropical Ecology.* April 16–21, 1979 Kuala Lumpur, Malaysia. The International Society of Tropical Ecology. 1383 pp.

*Notes:* Leaf and seed surface fungi of rice were monitored following the application of three fungicides and two insecticides. All pesticides reduced the number of leaf and seed fungi. Following the application there was an increased incidence of both numbers and species of *Curvularia*.

Lal, R., Lal, S. (eds.) (1988) *Pesticides and nitrogen cycle* vols. (1-3). CRC Press, Boca Raton, Ha., USA.

*Notes:* Topics covered include: Nature and habitats of microbes of N cycle. Experimental, methodological and analytical approach to study the effects of pesticides on N cycle. Effects on ammonification, nitrification, denitrification. Pesticides and N transformations in flooded soils. Effects on symbiotic nitrogen fixation. Effects on Rhizobium-Legume symbiosis. Effects on blue-green algae.

Mahapatra, R.N., Rajaramamohan Rao, V. (1981) Influence of hexachlorohexane on the nitrogenase activity of rice rhizosphere soil. *Plant Soil* 59(3): 473-478.

*Summary:* The influence of application of BHC to a submerged tropical field soil, at rates equivalent to recommended field rates (1-2.5 kg ai/ha) and twice this level, upon the rhizosphere soil nitrogenase,  $N_2$  fixers, and soil redox potential (Eh) was investigated. The rhizosphere soil from BHC-treated fields exhibited significantly higher nitrogenase activity than that from untreated fields. BCH retarded the drop in redox potential of the field soil up to eighty days after transplantation under submerged conditions. Populations of  $N_2$ -fixing *Azospirillum* sp. and *Azotobacter* to a greater extent and anaerobic organisms to a lesser extent, were stimulated in BCH-treated soils. Results indicate the stimulation of heterotrophic  $N_2$ -fixing bacteria by BCH in submerged paddy soils.

Mandal, B.B., Bandyopadhyay, P., Bandyopadhyay, S., Maity, S.K. (1987) Effect of some preemergence herbicides on soil microflora in direct seeded rice. *Indian Agric.* 31(1): 19-23. (NS)

*Notes:* Field experiment with microflora enumeration four, eleven, eighteen, and twenty-five days after application.

Mani, A., Prasad, N.N. (1978) Studies on the effect of phorate and disyston on nitrification in paddy soils. *Pesticides* 12(9): 33-34. (NC)

Marimuthu, T., Kandasamy, D., Oblisami, G., Subramaniam, T.R. (1975) Influence of foliar spray of certain pesticides on the phyllosphere microflora of paddy. *Sci. and Culture* 41(10): 490-492. (NS)

Mikkelsen, D.S. (1965) Use of chlorinated phenols as nitrification inhibitors in rice fertilization. *Rice J.* 68: 74. (NS)

Mitsui, S., Watanabe, I., Honda, S. (1962) Effect of pesticides on denitrification in paddy soil. I. *Jpn. J. Soc. Soil. Sci. Fert.* 33: 469–474.

*Notes:* Quoted in Azad and Khan (1968) Vapam depressed denitrification by about 40 percent when used at 20 ppm, whereas Dithane, BHC, and PCP caused less inhibition.

Mitsui, S., Watanabe, I., Honma, M., Honda, S. (1964) The effect of pesticides on the denitrification in paddy soil. *Soil Sci. Plant Nutr.* 10(3): 107–115.

*Summary:* Pot and laboratory experiments were conducted with the aim of examining the effect of pesticides and some other compounds on the denitrification in paddy soil. Konosu (Saitama Pref.) well drained alluvial paddy soil was used. Pot experiments revealed that Vapam and Dithane (Zheb) depressed the nitrification of urea dressed in soils under upland conditions. However, none of the pesticides examined (Vapam, Dithane, PCP, BHC) exerted a depressive effect on the denitrification of nitrate dressed under water-logged conditions. Vapam showed a remarkable promotion of the mineralization of soil nitrogen. After preincubation of air dried Konosu soil under anaerobic water-logged conditions in the laboratory, the added nitrate was rapidly disappeared, resulting in an approximately stoichiometric accumulation of gaseous products. The process of denitrification was measured by way of nitrate disappearance, nitrite accumulation, and evolution of gas other than  $\text{CO}_2$  and  $\text{O}_2$ . Among dithiocarbamate compounds, Vapam (20 ppm) remarkably inhibited the denitrification, namely, depressed the denitrification approximately by four tenths. At 100 ppm, dithiocarbamate compounds besides Vapam depressed the nitrate disappearance according to the following: Ziram < Dithane < Thiuram < Ferban < Maneb < Nabam. Diethyl dithiocarbamate did not show any depressive action on denitrification. Nabam and Maneb, both alkyldiamine dithiocarbamate compounds remarkably depressed the denitrification. Zinc salt of ethylene-bis-dithiocarbamate (Dithane) depressed the denitrification slightly more than dimethyl dithiocarbamate (Ziram). Respiratory inhibitors such as azide and monoiodoacetate showed remarkable depression of denitrification. N-Serve (2-chloro, 6-(trichloromethyl) pyridine) at 14 ppm revealed slight inhibition (about 30 percent) of denitrification. The action of PCP (50 ppm), BHC (40 ppm), sodium chlorate (100 ppm) were much less inhibitive. Dicyandiamide at 50 ppm was not inhibitive. The inhibition of nitrate disappearance was similarly reflected on the inhibition of gas evolution from nitrate. Nitrite was accumulated in proportion to the suppression of nitrate reduction except for azide and N-Serve, that is nitrite reduction is more

sensitive to pesticides than nitrate reduction. From the results described in this paper, it is concluded that soil denitrification is not so sensitive to pesticides as is nitrification.

*Notes:* Most of the chemicals are used at a concentration higher than that used in the fields.

Nair, K.S., Ramakrishnan, C., Sithanantham, S. (1973) Effect of soil application of insecticides on the nutrient status, bacterial population and yield in rice soils. *Madras Agric. J.* 60(7): 441–443.

*Summary:* Two field experiments were conducted during 1967–68 at the Agricultural College and Research Institute, Coimbatore, to find out the effect of soil application of sevidol, endrin and gamma BHC on the nutrient status and the bacterial population of the soil as observed at the time of harvest of the rice crop. At the dosages tried (0.45 to 2.25 kg ai/ha) none of three insecticides appeared to have any adverse effect on available N, P and K status of the soil. Also there could be observed no ill-effects on the bacterial population of the soil. Insecticidal application also resulted in significant increase in grain yields, the maximum increase being with sevidol, followed by endrin and gamma BHC.

Nair, K.S., Ramakrishnan, C., Sithanantham, S. (1974) Effect of soil application of insecticides of the nutrient status, bacterial population and yield in rice soils. *Indian J. Agric. Chem.* 7(1): 15–24.

*Summary:* Soil application of insecticides like sevidol, endrin and gamma BHC, are recommended for the control of rice stem borers. The present study consisted of two field experiments conducted during 1967–1968 at the Agricultural College and Research Institute, Coimbatore, to find out the effect of application of these insecticides on the nutrient status and the bacterial population of the soil as observed at the time of harvest of the rice crop. At the dosages tried (0.45 to 2.25 kg/ha) none of the three insecticides appeared to have any adverse effect on N, P and K status of the soil. Also there could be observed no ill-effects on the bacterial population of the soil. Insecticidal application also resulted in significant increase in grain yields, the maximum increase being with sevidol, followed by endrin and gamma BHC.

Nayak, D.N., Pasalu, I.C., Rajaramamohan Rao, V. (1980) Influence of natural and synthetic insecticides on nitrogen fixation ( $C_2H_2$  reduction) in the rice rhizosphere. *Curr. Sci.* 49(3): 118–119. (NS)

*Notes:* The only paper comparing pesticides of plant origin with synthetic pesticides.

Nayak, D.N., Rajaramamohan Rao, V. (1980) Pesticides and heterotrophic nitrogen fixation in paddy soils. *Soil Biol. Biochem.* 12(1): 1–4.

*Summary:* The effect of three pesticides, benomyl, carbofuran and gamma-BHC at 5 ppm, rates equivalent to recommended field levels, on the heterotrophic  $N_2$  fixation in five air-dried, cellulose-amended, submerged, tropical soils was investigated employing  $^{15}N$  tracer technique under laboratory conditions. Addition of benomyl, a carbamate fungicide, to alluvial, laterite and two acid sulphate soils resulted in significant increases in  $N_2$  fixation, while carbofuran, a methylcarbamate insecticide, exerted a stimulatory effect on  $N_2$  fixation in alluvial, laterite and acid saline soils. Gamma-BHC, a chlorinated hydrocarbon insecticide, stimulated  $N_2$  fixation in alluvial and acid sulphate pokkali soils, while considerable inhibition of  $N_2$  fixation was evident in other soils. Results showed differential responses of specific groups of  $N_2$ -fixing organisms to the pesticides depending on the soil type.

Nayak, D.N., Rajaramamohan Rao, V. (1982) Pesticides and nitrogen fixation in a paddy soil. *Soil Biol. Biochem.* 14(3): 207–210.

*Summary:* The influence of six pesticides, applied singly or in combination, on  $^{15}N_2$  incorporation and  $C_2H_2$  reduction in a submerged paddy soil was studied under laboratory conditions. While the application of diazinon had no marked effect, benomyl, carbofuran, parathion, nitrofen and -HCH, at concentrations close to recommended field application rates (5 g g<sup>-1</sup>) significantly stimulated  $N_2$  fixation. Synergistic stimulatory effects of the pesticides on  $N_2$  fixation were evident particularly in combinations of carbofuran with benomyl, nitrofen and -HCH. On the contrary, diazinon slightly retarded the stimulatory effect of benomyl and carbofuran. Results indicated that the differential effects of pesticides on  $N_2$  fixation could be attributed partly to fluctuations in the population of certain groups of  $N_2$  fixers in submerged soil.

Nayak, D.N., Rao, V.R. (1982) Pesticides and nitrogen fixation in a paddy soil. *Soil Biol. Biochem.* 14: 207–210.

*Summary:* The influence of six pesticides, applied singly or in combination, on  $^{15}N_2$  incorporation and  $C_2H_2$  reduction in a submerged paddy soil was studied under laboratory conditions. While the application of diazinon had no marked effect, benomyl, carbofuran, parathion, nitrofen and -HCH, at concentrations close to recommend field application rates (5 g/g) significantly stimulated  $N_2$  fixation. Synergistic stimulatory effects of the pesticides on  $N_2$  fixation were evident particularly in combinations of carbofuran with benomyl, nitrofen and -HCH. On the contrary, diazinon slightly retarded the stimulatory effect of



benomyl and carbofuran. Results indicated that the differential effects of pesticides on  $N_2$  fixation could be attributed partly to fluctuations in the population of certain groups of  $N_2$  fixers in submerged soil.

Nishio, M. (1961) Some new soil-microbiological problems accompanying with recent changes of agricultural systems in Japan. *Bull. Inst. Agric. Res. Tohoku Univ.* (Japan) 36(1): 67–75.

*Notes:* Among several problems caused by crop intensification, the authors report an abnormal growth (dwarfing) of rice in fields treated with benthicarb. This was found to be caused by a microbial metabolite: dechlorinated benthicarb whose production is accelerated by straw application.

Nishio, M., Kusano, S. (1978) Effects of long-term application of organophosphate insecticides on bacterial numbers and nitrification in soil. *J. Cent. Agric. Exp. Stn.* 28: 39–48 (In Japanese). (NS)

*Notes:* Nitrification in soils having received insecticide for four consecutive years was not significantly different from the control. Data on total bacterial populations neither show clear differences between soils treated at the recommended dose and the control. On the other hand count of bacteria tolerant to organophosphate insecticides were two to four times higher in treated soils.

Pal, S.S. (1981) Interaction between pesticides and microbial activities in submerged soils. Ph. D. thesis, University of Calcutta, India. (NC)

Pal, S.S., Misra, A.K., Sethunathan, N. (1980) Inhibition of the reduction of flooded soils by hexachlorocyclohexane. *Soil Sci.* 129: 54–55.

*Summary:* In a study on the effect of hexachlorocyclohexane (HCH) on soil transformations in flooded soils, 5 percent granules of HCH were added to three soils to provide final concentrations of 5 to 100 parts per million of active ingredient, and the soils were flooded. Addition of HCH even at the 5-ppm level led to a remarkable decrease in formation of  $Fe^{2+}$  and, to a lesser extent, soluble manganese and prevented the drop in redox potentials in all soils. These effects of HCH were well pronounced also in the presence of added rice straw (0.5 percent), although rice straw alone hastened soil reduction. The inhibitory effect of HCH on soil reduction lasted even after 50 days of flooding.

Pal, S.S., Sudhakar-Barik, Sethunathan, N. (1979) Effects of benomyl on iron and manganese transformations in flooded soil. *J. Soil Sci.* 30: 155–159. (NS)

Palaniappan, S.P., Balasubramanian, A. (1985) Influence of two pesticides on certain soil enzymes. *Agric. Res. J. Kerala* 23(2): 189–192. (NS)

*Notes:* At recommended dose no marked effect on soil enzymatic activities but higher concentrations have often a negative impact.

Patnaik, N.C., Panda, N., Dash, P.C. (1986) Effects of 6 granular insecticides on rice rhizosphere microflora in India. *Int. Rice Res. Newsl.* 11(4): 30–31. (NS)

*Notes:* Even if differences in populations of microorganisms are significant they are most often not very marked.

Purushothaman, D., Venkataraman, C.V., Kasirajan, C. (1976) Attendant changes in the microflora of ricefield soil as influenced by the application of granular insecticides. *Madras Agric. J.* 63(8/10): 515–519.

*Summary:* The influence of six granular insecticides, viz. diazinon, cytolane, carbofuran, carbaryl + lindane, quinalphos and Dursban on the quantitative changes in the microbial population of ricefield soils was studied. When applied at recommended doses (1.5 kg ai/ha) there was no deleterious effect on the fungal population due to the insecticides. Among the different insecticides, there was no significant difference in respect of their influence on the microbial population. The same inference held true with actinomycetes. However, the bacterial population underwent a significant fall due to the insecticidal application. When the activities of soil enzymes like phosphatase, b -glucosidase and invertase were determined following the insecticidal application, b -glucosidase alone was significantly inhibited and other enzymes recorded no change.

Raghu, K., MacRae, I.C. (1967a) The effect of gamma isomer of benzene hexachloride upon the microflora of submerged rice soils. I. Effect upon algae. *Can. J. Microbiol.* 13: 173–180. (NS)

Raghu, K., MacRae, I.C. (1967b) The effect of gamma isomer of benzene hexachloride upon the microflora of submerged rice soils. II. Effect upon nitrogen mineralization and fixation and selected bacteria. *Can. J. Microbiol.* 13: 621–621.

*Summary:* The effect of applications of benzene hexachloride (-BHC) to two submerged tropical soils at rates equivalent to recommended field practice (5 kg/ha) and 10 times this level upon the mineralization of native soil nitrogen was studied. No inhibitory effect on nitrogen mineralization was detected. A significant increase in the amount of nitrogen mineralized was detected in one of the soils over a period of 16 weeks of submergence. Additions of -BHC at 6 kg/ha

resulted in significant increases in nitrogen fixation in both soils. Populations of anaerobic, phosphate-dissolving bacteria were found to be higher in the two soils when they were treated with -BHC at 6 kg/ha.

Ramakrishna, C., Gowda, T.K.S., Sethunathan, N. (1979) Effect of benomyl and its hydrolysis products, AB and MBC on nitrification in flooded soil. *Bull. Environ. Contam. Toxicol.* 21: 328–333. (NS)

Ramakrishna, C., Rao, V.R., Sethunathan, N. (1978) Nitrification in simulated oxidized surface of flooded soil amended with carbofuran. *Soil Biol. Biochem.* 10: 555–556. (NS)

Ramakrishna, C., Sethunathan, N. (1982) Stimulation of autotrophic ammonium oxidation in rice rhizosphere soil by the insecticide carbofuran. *Appl. Environ. Microbiol.* 44(1): 1–4.

*Summary:* The application of the insecticide carbofuran (technical or formulated) to rice rhizosphere soil suspensions at 10 and 100 ppm ( $\mu\text{g/ml}$ ) of active ingredient distinctly stimulated the autotrophic oxidation of ammonium. Evidence suggested that *Nitrosomonas* sp. was enriched in the presence of carbofuran. Formulated carbofuran (Furadan 3G) exhibited by technical-grade (99.5 percent) carbofuran, a result which was attributed to the  $\text{CaCO}_3$  present in the formulation.

Ramakrishna, C., Sethunathan, N. (1983) Inhibition of heterotrophic and autotrophic nitrification in bacterial cultures by carbaryl and 1-naphthol. *J. Appl. Bacteriol.* 54: 191–195.

*Summary:* A carbamate insecticide, carbaryl, and its hydrolysis product, 1-naphthol, inhibited nitrification by a heterotrophic bacterium, a *Pseudomonas* sp., at a concentration of 50 g/ml and by chemoautotrophic bacteria, a *Nitrosomonas* sp. and a *Nitrobacter* sp., at a concentration of 10 g/ml, in pure cultures.

Rao, J.L.N., Pasalu, I.C., Rajaramamohan Rao, V. (1983) Nitrogen fixation ( $\text{C}_2\text{H}_2$  reduction) in the rice rhizosphere soil as influenced by pesticides and method of their application. *J. Agric. Sci., Camb.* (G.B.) 110(3): 637–642.

*Summary:* The effect of pesticides on nitrogenase activity in rhizosphere soil from ricefields was investigated. The differential response of insecticides on nitrogenase depended on the method of field application. Results also showed that the differential response to the pesticides of specific groups of  $\text{N}_2$ -fixing microorganisms depended upon the method of application. Soil incorporation of

carbofuran stimulated the rhizosphere nitrogenase, while endosulfan and hexachlorocyclohexane inhibited it. Carbofuran and hexachlorocyclohexane stimulated nitrogenase when applied to the standing water. Seedling root dips of isofenphos stimulated nitrogenase, while endosulfan, BPMC and carbaryl showed a variable effect. Quinalphos inhibited nitrogenase irrespective of method of application.

Rao, J.L.N., Prasad, J.S., Rajaramamohan Rao, V. (1984) Nitrogen fixation ( $C_2H_2$  reduction) in the rice rhizosphere soil as influenced by pesticides and fertilizer nitrogen. *Curr. Sci.* 53(21): 1155–1157. (NS)

Ray, R.C. (1981) Microbial activities in the rhizosphere of rice plants as influenced by pesticide applications. Ph.D. thesis, Utkal University, Bhubaneswar. (NC)

Ray, R.C., Ramakrishna, C., Sethunathan, N. (1980) Nitrification inhibition in a flooded soil by hexachlorocyclohexane and carbofuran. *Plant Soil* 56: 165–168.

*Summary:* The effect of a commercial granular formulation of hexachlorocyclohexane (HCH) on nitrification in a flooded soil was studied at 10 and 100 ppm ai. The oxidation of the added ammonium to nitrate was inhibited significantly at 10 ppm and almost completely at 100 ppm, concomitant with a proportional decrease in the populations of ammonium- and nitrite-oxidizing autotrophic bacteria. Of special interest is the synergistic increase in the inhibition of nitrification by a combined application of HCH and carbofuran.

Ray, R.C., Sethunathan, N. (1980) Effect of commercial formulation of hexachlorocyclohexane and benomyl in the oxidation of elemental sulfur in soils. *Soil Biol. Biochem.* 12: 451–453. (NS)

Ray, R.C., Sethunathan, N. (1988) Pesticides and nitrogen transformations in flooded soils. Pages 119–142 in R., Lal, Lal S. (eds.), *Pesticides and nitrogen cycle* (vol. 2.). CRC Press, Boca Raton, Ha., USA.

*Summary:* It is clear from the above survey that reports on the side effects of pesticides on microorganisms and their activities in flooded soils are not consistent. Conflicting reports of the same pesticide exhibiting innocuous, inhibitory, and stimulatory effects on a specific microorganism and its activity are not uncommon in literature. Because, methodology used in many of these studied is not uniform especially with regard to the concentration of the pesticide, formulation of the pesticide, the incubation conditions, sampling procedure, analytical

techniques, and criteria used in evaluation of the side effects. In studies with formulations, a question arises whether the observed effects are due to the active ingredient, carrier in the formulation or synergistic interaction between the carrier and formulation. There are reports of synergistic interactions between a pesticide and carrier in the formulation, increasing the toxicity to insects. Evidently, for a meaningful conclusion, there is a need to generate data on the side effects from simultaneous studies with formulated and technical or analytically pure pesticide. Again, for chemically and/or biologically unstable pesticides such as carbamate and organophosphorus groups, the observed side effects after application of parent molecule may be due to their breakdown products and not necessarily due to the parent molecule. 1-Naphthol, hydrolysis product of carbaryl, is more toxic than carbaryl to certain microorganisms and their activities. Unfortunately in the experimental design and in the interpretation of results, the role of breakdown products of specially unstable insecticides is often neglected. In majority of studies on the side effects of pesticides, data were generated under laboratory conditions using relatively high concentration of pesticides. Extrapolation of these results to actual field conditions is therefore questionable. Pure culture studies may not have much relevance since in nature a vast range of microorganisms interact with each other and the net effect on microbial community is more important than the effect on individual microorganisms. This is particularly true in transformations such as denitrification and nitrogen fixation, which are carried out by a myriad of taxonomically different microorganism. Despite the inconsistency and several differences in the reported studies, certain definite conclusions are possible. Contrary to the common belief that pesticides applied at recommended levels and intervals seldom affect, adversely or beneficially, the microbial processes, certain pesticides such as carbofuran even when applied to the soil at recommended level effected striking stimulation of nitrogen fixation and autotrophic oxidation of ammonium. Likewise, there is convincing evidence in support of significant interactions between pesticides in a combination, as for instance carbofuran and HCH applied at individually subtoxic levels leading to increased toxicity to nitrification. There is an urgent need to demonstrate these and other side effects of pesticides in a more complete model ecosystems comprising various biotic and abiotic components of a flooded ricefield. Such microcosm studies would help in a better understanding of the significance of the interactions of the pesticide with the microbial community in the nutrient-rich rhizosphere soil and overall impact of such interactions on soil fertility.

Roy, P., Sinha, P.K., Mukherjee, N. (1975) Effect of granular insecticides on rice soil microflora. *Indian J. Entomol.* 37(1): 93–95. (NS)

*Notes:* Inhibitory effects of diazinon, carbofuran, and endosulfan at recommended dose were observed on microbial populations at 3 and 9 DAA but they recovered at 20 DAA. Diazinon had a promoting effect on fungal populations.

Russo, S. (1970) Effects of some pesticides on the solubility of nutrients in submerged soil. *Riso* 19(1): 37–54.

*Summary:* An experiment has been carried out to study the influence of some chemical used as pesticides, namely potassium azyde, Ordram, and A-40 Dithane, on the availability of nutrients in flooded soil. The chemicals have been confronted with a untreated test at the following doses: Potassium azyde, 4, 6, and 10 kg/ha; Ordram, 55, 65, and 80 kg/ha; Dithane A-40, 8, 10, and 15 kg/ha. For every treatment three replications were carried out in pots, containing soil carefully mixed with the chemical, and submerged with daily addition of water to compensate the evaporation. Every 20 days, and for a total period of 80 days, a soil sample was analyzed for  $\text{NH}_4$ exchangeable, soluble  $\text{P}_2\text{O}_5$ , soluble  $\text{K}_2\text{O}$ , and organic matter. The effect of Dithane A-40 on the  $\text{NH}_4$ availability has been superior to that of potassium azyde. The action of Ordram, on the contrary, has been negative. The P availability has been increased, both with K azyde and with Ordram, whereas the positive effect of Dithane has been observed only with the lowest doses. At all levels, the three pesticides has favored the solubility of K. The decomposition of organic matter has been loosened by all the chemical. However, the algal development may have interfered with the process. It is suggested that effects observed on the solubility of nutrients is possibly correlated with phenomena of stimulation and inhibition of the soil microorganisms. The P availability, on the other hand, may have been affected also by the capacities of the active chemical groups of the pesticides to substitute for P ions, freed from stable combinations of the soil constituents.

Russo, S. (1971) Effects of insecticides on the biological factors in submerged ricefields. *Riso* 20(4): 331–349.

*Summary:* The effects of insecticides on the soil are examined in the present paper. Particular attention is given to the balance of the microbial population, to the biochemical processes affecting the mobility of nutrients, to the enzymatic activity of the soil. Studies carried out until now emphasize the necessity to maintain the biological balance of the soil in order to safeguard the normal biochemical processes affecting the fertility. The results of researches about the behavior of insecticides in submerged soils are discussed. It has already been ascertained that the degradation of some insecticides is faster in flooded fields than under normal agronomic conditions. Furthermore, it seems that insecticides

may affect the biochemical anaerobic processes, determining changes in the mobility of the nutrients.

Sahrawat, K.L. (1975) Effects of pesticides on nitrogen fixation. *Pesticides* 9: 21-23. (NC)

Sandhu, K.S., Randhawa, K.S., Chahal, V.P.S. (1978) The effect of some herbicides on the rhizosphere microflora in the seed crop of okra *Abelmoschus esculentus* (L.) Moench. *Indian J. Ecol.* 5(1): 61-66.

*Summary:* The bacterial population was higher in three controls, i.e., control weeded, unweeded and handpulling, than that in all herbicidal treatments. Alachlor at 1.94 kg ai/ha resulted in a significant increase in the actinomycetes population, whereas alachlor at 2.50 kg ai/ha, EPTC [S-ethyl N, N-dipropyl thiolcarbamate] + alachlor at 3.75 + 1.25 kg ai/ha, respectively, and fluchloralin at 1.20 and 0.90 kg ai/ha were on a par with the controls, handpulling and unweeded. The fungal population was relatively unaffected by the various herbicidal treatments, except nitrofen + linuron at 1.25 + 0.25 kg ai/ha, EPTC at 0.75 kg ai/ha, dichlormate at 5.00 kg ai/ha, EPTC + nitrofen at 3.75 + 0.62 kg ai/ha, and nitrofen at 1.25 kg ai/ha which caused a significant reduction in the fungal population as compared with that in the controls.

Sathasivan, K., Palaniappan, S.P., Balasubramaniyan, P. (1982) Effect of insecticide application on nitrogen transformation in flooded soil. *Int. Rice Res. News.* 7(1): 19. (NS)

Sato, K. (1985) Effect of pesticide on soil microorganisms. *Shokucho* 19(6): 2-17 (In Japanese). (NS)

Sato, K. (1986) Effect of pesticide on soil microorganism with special reference to herbicide and microflora. *Shokucho* 20(1): 3-19 (In Japanese). (NS)

Sato, K. (1987) Seasonal population changes of several bacterial groups in paddy soil in relation to application of a herbicide, benthocarb. *Bull. Inst. Agric. Res. Tohoku Univ.* 38(2): 69-82.

*Summary:* Population changes of several bacterial groups were surveyed in relation to the application of a herbicide, benthocarb (S-chlorobenzyl diethylthiocardamate). Changes in the amount of  $\text{NH}_4\text{-N}$  and dissipation of benthocarb were also followed: (1) counts of total viable bacteria and Gram-negative

bacteria gradually increased after water-logging. The increase was followed by a gradual decrease after the flowering period of rice plant. This trend of changes in the counts was very similar to that observed previously in the paddy field soil. Benthocarb application enhanced the initial increase in both the counts, but it did not affect the counts thereafter; (2) counts of ammonifying, nitrate-reducing and denitrifying bacteria changed irregularly during the surveying period as observed previously. Benthocarb application increased the initial increase in the counts of all of the bacterial groups as well; (3) the numbers of ammonium-oxidizing bacteria and nitrite-oxidizing bacteria increased at the initial period after water-logging. However, benthocarb inhibited the initial increase in accordance with the amounts of benthocarb. After the inhibition of the initial increase by the herbicide the numbers changed similarly in all the plots regardless of the application of the herbicide; (4) drainage of the plots of the paddy field where the dwarfing of rice plants occurred did not affect the pattern of the population changes of several bacterial groups except nitrifying bacteria whose numbers slightly increased after drainage; (5) the amount of ammonium-N decreased after water-logging, and its initial decrease was conspicuous in the plots applied with ten times of recommended rate (10 r. r.) of benthocarb. Drainage decreased the amount of ammonium-N as well; (6) benthocarb dissipated after water-logging and its decrease was remarkable in July when temperature was elevated. Dechlorinated benthocarb was accumulated in the plots applied with 10 r. r. of the herbicide, but was not detected in the plots applied with recommended rate (r. r.) of the herbicide in site of dissipation of the compound; (7) there was a marked difference in the values of yield components of rice plant between the two groups of plots; one applied with 10 r. r. and the other with r. r. of benthocarb. The yield components were very similar between the plots with r. r. of benthocarb and without the compound. These phenomena corresponded very well to the dwarfing which can be caused by the accumulation of dechlorobenthocarb.

Sethunathan, N., Macrae, I.C. (1969) Some effects of diazinon on the microflora of submerged soils. *Plant Soil* 30(1): 109–112.

*Summary:* The application of diazinon, an organophosphorus insecticide, at the rate of 2 kg and 20 kg active ingredient per hectare to submerged Maahas clay significantly stimulated the actinomycete population. A distinct zone of brown pigmentation formed in that part of the profile commonly referred to as the oxidized layer. A profuse growth of actinomycetes developed from the soil samples of this pigmented zone when streaked onto the nutrient agar. A visible increase in algal populations was noted in the standing water of the diazinon-treated soil.



Sethunathan, N., Pathak, M.D. (1971) Development of a diazinon-degrading bacterium in paddy water after repeated applications of diazinon. *Can. J. Microbiol.* 17: 699–702.

*Summary:* A decline in the brown planthopper control effectivity of diazinon was noticed after its continuous application to rice paddies for three one-half years at the International Rice Research Institute. In a study undertaken to determine the factor involved in this decline, rapid inactivation of diazinon was recorded within three to five days of its incubation with water from a ricefield that had received several applications of diazinon. During the same period, its degradation in water from an untreated ricefield was non-significant. This indicated the development of a degrading agent in paddy water following diazinon treatments. The inactivation of diazinon on incubation with water from treated fields was retarded if the incubation mixture was sterilized or kept anaerobically. Release of  $^{14}\text{CO}_2$  from  $^{14}\text{C}$ -diazinon was rapid from water of treated fields, but was inhibited when streptomycin was added to the system. A lag of two or three days, followed by a rapid degradation, was generally evident. Thus these data established the fact that aerobic biological agents, capable of degrading diazinon in paddy water, develop after diazinon application. A bacterium, *Arthrobacter* sp., capable of metabolizing diazinon in the presence of ethyl alcohol or glucose was isolated from paddy water of treated fields.

Sethunathan, N., Siddaramappa, R., Siddaram Gowda, T.K., Rajaram, K.P., Barik, S., Rao, V.R. (1976) Pesticide-soil microflora interactions in flooded rice soils. Pages 27–36 in *Trace contaminants of agriculture, fisheries and food in developing countries*. Vienna: International Atomic Energy Agency (IAEA).

*Summary:* Isotope studies revealed that gamma and beta isomers of HCH (hexachlorocyclohexane) decomposed rapidly in nonsterile soils capable of attaining redox potentials of -40 to -100 mV within 20 days after flooding. Degradation was slow, however, in soils low in organic matter and in soils with extremely low pH and positive potentials, even after several weeks of flooding. Under flooded conditions, endrin decomposed to six metabolites in most soils. There is evidence that biological hydrolysis of parathion is more widespread than hitherto believed, particularly under flooded soils conditions. Applications of benomyl (fungicide) to a simulated-oxidized zone of flooded soils favoured heterotrophic nitrification.

Setter, T.L., Waters, I. (1987) *Guide for environmental measurements on rice*. School of Agriculture, University of Western Australia, Nedlads, Western Australia. 6009. 32pp. (NS)

*Notes:* A compilation of classical methods for biological measurements in ricefields which might be used for assessing pesticide impacts.

Sidorenko, O.D., Klyuchareva, N.N., Nitse, L.K. (1986) Nitrogen-fixing activity of soil samples in ricefields after application of herbicides and straw. *Izv. Timiryasev S-KH. Akad.* 5: 188–191 (in Russian). (NS)

Simon-Sylveste, G., Fournier, J.C. (1979) Effects of pesticides on the soil microflora. *Adv. Agron.* 31: 1–92. (NS)

*Notes:* A review dealing mostly with upland soils. More than 500 refs are listed.

Singh, R.P., Rana, R.S., Carg, G.K. (1986) Effect of sevidol on nitrification under submerged conditions. *Pesticides* 20(2): 52–54.

*Summary:* In view of the importance of nitrogen cycle, the present study was carried out to see the effect of sevidol on nitrifying bacteria in simulated water logged soil under laboratory conditions. Sevidol at higher concentration (2 kg ai/ha) stimulated the  $\text{NO}_2\text{-N}$  formation without affecting the  $\text{NO}_3\text{-N}$  level in the soil. However, sevidol at lower (0.5 kg ai/ha) and field recommended concentration (1 kg ai/ha) did not affect the nitrification process in the soil.

Sivaraj, K., Venugopal, MS. (1979) Influence of mephosfolan on the rhizosphere microflora of rice grown in different soil types. *Pesticides* (Nov.): 23–26.

*Summary:* Mephosfolan 0.75 and 1.0 kg ai/ha increased the bacterial population in Lower Bhavani soil while a decrease was recorded in Aduthurai and Coimbatore soils. In general, mephosfolan application increased the actinomycete population in Lower Bhavani and Coimbatore soils while a reduction was noted in Aduthurai soil. There was a reduction in the fungal population at all stages in Aduthurai and Coimbatore soil although variations were observed in Lower Bhavani soils while a general reduction was observed in Coimbatore soil.

Sivasithamparam, K. (1970) Some effects of an insecticide (“Dursban”) and a weedicide (“Linurion”) on the microflora of a submerged soil. *Riso* 19(4): 339–346.

*Summary:* Microbiological analyses of a submerged soil treated with an insecticide (Dursban) and a weedicide (Linuron) showed inhibition of the two groups of nitrifiers at the time of the first sampling (at 3 weeks), and a recovery in their numbers at the time of the second sampling (at 3 months). There was a general stimulation of aerobic bacteria, actinomycetes, ammonifiers, sulphate reducers,

cellulose decomposers and heterotrophic iron precipitators by both the chemicals at both time of sampling. Both treatments generally depressed denitrifiers. Anaerobic N fixers were stimulated by both the chemicals three weeks after treatment. Dursban showed a temporary inhibitory effect on aerobic P dissolvers, and a stimulation of anaerobic P dissolvers at the second sampling. The insecticide also markedly inhibited aerobic N fixer at the latter stage. Linuron showed stimulation of fungi at both samplings and aerobic N fixers at the second sampling. The weedicide appeared to have an inhibitory effect on anaerobic N fixers. The treatment with Dursban resulted in a visible increase in the algal population while the weedicide treatment resulted in a visible suppression of the organisms.

Somerville, H.J. (1978) Pesticides, microorganisms and the environment. *Span.* 21(1): 35–37. (NS)

Sudhakar-Barik, Ramakrishna, C., Sethunathan, N. (1979) A change in the degradation pathway of parathion after repeated application to flooded soil. *J. Agric. Food Chem.* 27: 1391–1392.

*Summary:* The degradation pathway of parathion shifted to hydrolysis from reduction after repeated applications of parathion or its hydrolysis product, p-nitrophenol, to a flooded soil. This shift occurred as a result of the proliferation of parathion-hydrolyzing microorganisms that utilized p-nitrophenol as the energy source. This is probably the first report of the enrichment of a population capable of degrading a parent molecule upon application of the primary product of its metabolism.

Swamiappan, M., Chandy, K.C. (1975) Effect of certain granular insecticides on the nodulation by nitrogen-fixing bacteria in cowpea (*Vigna sinensis* L.). *Curr. Sci.* 44(15): 558–559. (NS)

Takaku, T., Takahashi, M., Otsuki, A. (1979) Dispersion of an organophosphorus insecticide, fenitrothion in paddy fields and its effects on the microorganisms. *Jap. J. Limnol.* 40(3): 137–144 (In Japanese). (NS)

Tirol, A.C., Santiago, S.T., Watanabe, I. (1981) Effect of the insecticide carbofuran on microbial activities in flooded soil. *J. Pestic. Sci.* 6: 83–90.

*Summary:* The effects of carbofuran on some soil microbial activities—nitrogen mineralization, nitrification, N<sub>2</sub> fixation by blue-green algae, and urea hydrolysis—were investigated in the laboratory and the greenhouse. The addition of 10 g ai carbofuran per gram dried soil had no inhibitory effect on the

mineralization of native soil nitrogen. Nitrifying activity was enhanced in flooded soil treated with 10, 20, 50, and 100 ppm ai carbofuran. Nitrifying activity increased with increasing carbofuran concentration. The growth of blue-green algae was promoted by addition of 6 kg ai carbofuran/ha to the floodwater. Subsequently, a marked increase in the acetylene reduction activity of carbofuran-treated floodwater was obtained. Turbidity and an abundance of green algae distinguished the untreated floodwater from the carbofuran-treated one. The positive effect of carbofuran on phototrophic  $N_2$ -fixation appeared after its decomposition. The addition of up to 15 ppm ai ( $\mu\text{g/ml}$  floodwater) carbofuran had no effect on the acetylene-reduction activity of *Gloeotrichia* sp., but 20 ppm ai caused a significant lowering of that activity. The rate of urea hydrolysis appeared to be faster in dryland than in flooded soil. The addition of 50 ppm ai carbofuran did not affect the rate of urea hydrolysis.

Tu, C.M. (1978) Effect of pesticides on acetylene reduction and microorganisms in a sandy loam. *Soil Biol. Biochem.* 10(6): 451-456.

*Summary:* A study was made of the effects of thirty-two pesticides at two concentrations on nitrogenase activity ( $C_2H_2$  reduction).  $N_2$  fixers, bacteria and fungi in an agricultural sandy loam. Chlorfenvinphos, chlorpyrifos, carbofuran, metalkamate and permethrin at both rates, and ethoprop, leptophos and chlordane at the high rate depressed  $C_2H_2$  reduction. The population of  $N_2$  fixers was not suppressed significantly. Bacterial and fungal populations initially decreased with some pesticide treatments but recovered rapidly to levels similar to or higher than those in the controls.

Tu, C.M. (1979) Influence of pesticides on acetylene reduction and growth of microorganisms in an organic soil. *J. Environ. Sci. Health Part B Pestic. Food Contam. Agric. Wastes* 14(6): 617-624.

*Summary:* The effects of thirty-two pesticides at two concentrations on acetylene reduction (non-symbiotic nitrogen fixation), nitrogen fixers, bacteria and fungi in an organic soil were assessed. None of the pesticide treatments suppressed  $C_2H_2$  reduction as compared to controls. No significant inhibition of the population of non-symbiotic nitrogen fixers occurred. However, stimulatory effects were observed with treatments of fensulfothion, fonofos, oxamyl, DDR, Telone R and Telone CR. Bacterial and fungal populations showed temporary declines but all recovered within 7 days to levels similar to or higher than those in the controls.

Tu, C.M., Miler, J.R.W. (1976) Interactions between insecticides and soil microbes. *Residue Rev.* 64: 17-65.

*Summary:* A survey has been made of the known inhibitory effects of insecticides on microorganisms. Some recent work on the degradation of insecticides is also included. Many of the various chemicals used as insecticides apparently have little effect on soil microorganisms under certain conditions. The toxicity of the chemicals may manifest itself in reduction of microbial growth rate, basic activity in metabolism and reproduction. Investigations so far, however, indicate that when insecticides are used at recommended field rates these chemicals will not significantly reduce indigenous microbial activities that are important in soil fertility, and in some cases they are stimulatory. Excessive applications may be temporarily depressive. Certain microbes may become adapted to the chemicals. In a less competitive environment, by utilizing the dead cells of the organisms killed by the insecticide, they reach very high numbers. The population of organisms capable of degrading insecticides, therefore, increases dramatically as a result of insecticide application. The extent of the degradation depends on numerous factors. All organisms, but particularly aquatic microorganisms, absorb and concentrate insecticides from their environment. Although several workers have demonstrated that soil microorganisms are able to degrade even the most stable and persistent organic insecticides, no one has yet demonstrated that these compounds serve as nutritional or energy sources for organisms leading to elimination of the compounds from the environment. Little is known about the metabolism of insecticides at any level. It appears that many microorganisms can metabolize the insecticides to some extent, but in some cases this limited metabolism leads to the production of even more toxic and persistent substances. Some organochlorine insecticides such as BHC, DDT, aldrin, heptachlor, dieldrin, toxaphene, and chlordane are highly resistant to degradation in soil and remain in the soil for long periods of time as residues. The addition of biodegradable organic material to the soil will enhance the growth of certain groups of microorganisms and influence insecticidal chemical reactions as a result of stimulated microbial activity and changes in soil aeration. Evidence shows that anaerobiosis of soil microorganisms stimulates the degradation of many insecticides. Exceptions are heptachlor epoxide and dieldrin, which are very persistent in both aerobic and anaerobic environments. Certain microorganisms possessing wide-spectrum enzymes might be able to degrade such insecticides. Organophosphorus and carbamate insecticides or their degradation products are readily metabolized by bacteria, actinomycetes, fungi, and algae in soil. To date, much of this work has been confined to laboratory studies and has yet to be translated into the development of more effective measures in the reduction of insecticidal residue in the field.

Turner, F.T., (1979) Soil nitrification retardation by rice pesticides. *Soil Sci. Soc. Am. J.* 43(5): 955-957.

*Summary:* The effectiveness of selected rice pesticides carbofuran, propanil, bifenox and sodium azide in comparison to nitrogen and terrazole in retarding soil nitrification was evaluated by determining increases in nitrate-N concentrations and/or decreases in ammonium-nitrogen concentrations. In a vertisol to which 50 ppm ammonium-N had been added and pesticide applied at recommended application rates, all compounds showed evidence of nitrification inhibition during the first 10 days of incubation. After 60 days incubation, only bifenox, sodium azide, terrazole, and nitrapyrin were still retarding nitrification. Similarly in another experiment the pesticides, applied at one-half to 10 times the recommended application rate, were not as effective as nitrapyrin and terrazole in retarding nitrification in a moist alfisol and vertisol; yet, each pesticide exhibited some nitrification inhibition, especially at the excessive application rate. The effectiveness of the individual pesticides in retarding nitrification varied with soil type. These rice pesticides have potential to retard nitrification that should be recognized when studying N transformations in soils or when studying the effect of pesticides on plants grown in soil.

Wainright, M. (1978) A review of the effects of pesticides on microbial activity in soils. *J. Soil Sci.* 29: 287–298.

*Summary:* The paper reviews the recently published literature (mainly since 1970) on the effects of pesticides on the major biogeochemical cycles in soils, including transformations of carbon, nitrogen, phosphorus sulphur, trace elements and soil enzymes. The main conclusion is that pesticides, with the exception of fumigants and some broad spectrum fungicides, have little deleterious influence on soil processes when applied at field rates. Obvious gaps in our knowledge of pesticide-soil interactions are pointed out and suggestions are made where future research is needed.

Wardle, D.A., Parkinson, D. (1990) Influence of the herbicide glyphosate on soil microbial community structure. *Plant Soil* 122(1): 29–38.

*Summary:* The side effect of glyphosate on the soil microflora were monitored by applying a range of glyphosate concentrations (0, 2, 20 and 200 µg/g herbicide) to incubated soil samples, and following changes in various microbial groups over twenty-seven days. Bacterial propagule numbers were temporarily enhanced by 20 µg/g and 200 µg/g glyphosate, while actinomycete and fungal propagule numbers were unaffected by glyphosate. The frequency of three fungal species on organic particles in soil was temporarily enhanced by 200 µg/g glyphosate, while one was inhibited. One species was temporarily enhanced on mineral particles. However, many of these fungi were inhibited by 200 µg/g

glyphosate in pure culture. There was little agreement between species responses to glyphosate in incubated soil samples and in pure culture.

Watanab, I. (1978) Pentachlorophenol (PCP) decomposing activity of field soils treated annually with PCP. *Soil Biol. Biochem.* 10: 71–75.

*Summary:* Soil from field plots (Hokkaido Agricultural Experiment Station, Memuro, Japan) that had been treated once a year with pentachlorophenol (PCP) and from untreated plots was tested for PCP-decomposing activity in the laboratory. When PCP as an aqueous solution of pentachlorophenolate was added to both sets of soil samples, no significant difference was noticeable in the PCP-decomposing activity, despite a 1,000-fold difference in the number of PCP-decomposing microorganisms. When PCP was added as a PCP-celite mixture, however, PCP-decomposing activity was related to the history of the plot's treatment. The activity of the soil from PCP field plots was consistently higher than that from non-treated plots. When PCP was added to the untreated soil and incubated, the number of PCP-decomposing microorganisms increased, reaching the same order as that of PCP-treated soil plots after 3–4 weeks.

# APPENDIX F

## ANNOTATED BIBLIOGRAPHY ON THE EFFECTS OF PESTICIDES ON HUMAN HEALTH IN RICE-GROWING AREAS

R.D. Valmonte-Gerpacio

Agarwal, H.C. (1978) Pesticide residues in man. Paper presented at a symposium on pesticide residues in the environment in India, held at the University of Agricultural Sciences, Hebbal, Bangalore, India, sponsored by FAO/UNESCO/UNDP/ICAR/UAS, November 1978. UAS Tech. Series No. 32. Edwards, C.A., Veeresh, G.K., Krueger, H.R. (eds.).

Pesticides used to control agricultural insect pests and insect vectors of diseases has resulted in the accumulation of persistent chemicals in the environment. These pesticides have found their way into aquatic systems and food chains. Significant quantities of pesticide residues have been detected in human bodies all over the world. DDT and its metabolites, particularly DDE, were found in most human populations and usually total DDT residues (including *p,p'*-DDT and various metabolites) were less than 10 ppm. They were higher in Israel at up to 18 ppm. Residues were comparatively high in Italy (15.4 ppm), Spain (15.7 ppm), and one group in USA (14.4 ppm); DDE accounted for bulk of the total DDT residues, from 43 to 86 percent. Organochlorine pesticides detected in human adipose tissue included dieldrin, HCH, heptachlor epoxide and endrin, but their concentration was found much less than DDT. Organochlorine pesticide



residues have also been detected in human blood, with total DDT concentration at about 50 ug/L.

It has been reported that the body fat and blood of people from India contains higher levels of pesticide residues than those from other countries. Adipose tissues from certain areas contained more than 20 ppm of total DDT. The mean value for total DDT in the blood of Delhi men was 0.284 ppm and was 0.246 ppm for the women, both higher than those from other countries. In addition to DDT, residues of beta-HCH and dieldrin have also been reported.

Castañeda, C.P., Cortes-Maramba, N.P. (1986) A study on occupational exposure to cholinesterase-inhibiting compounds among Filipino rice farmers, San Leonardo, Nueva Ecija, Philippines. *Medical Currents* (Nov.–Dec.) 19: 4–6.

One hundred rice farmers from five barangays were visited before and after pesticide application. On the average the farmers had been using pesticides for 11.8 years; 39 percent had been using it for six to ten years, and 34 percent, for eleven to fifteen years. Thirty nine percent of the farmers were exposed for six to 15 hours to category I and II pesticides during the season. There was pre-exposure depression of blood cholinesterase in four percent of the samples, and postexposure depression in 6 percent. Thirty-eight percent had low hemoglobin levels; 76 percent had abnormal eosinophils; and 13 percent had abnormal thrombocytes. There was significant differences in sweating before and after exposure.

Castañeda, C.P., Maramba, N.C., Ordas, A. (1988). *A field worker exposure study to methyl parathion among selected rice farmers, Malolos, Bulacan, Philippines*. A report submitted to International Development Research Center (IDRC) and Fertilizer and Pesticide Authority, Manila, Philippines (FPA).

Forty five randomly selected farmer-volunteers, were divided into eight groups corresponding to eight pesticide-related activities: mixing and loading; spraying; cleaning and disposal; days one and seven reentry; and a group who did all activities. Methyl parathion 50EC was applied at approximately 327 to 467 grams ai/ha. Potential dermal penetration through the protective clothing material was highest for the group doing all activities (46.84 percent). Regional exposure was predominant in the hands (23 to 73 percent) for all field activities. Potential dermal contamination was highest during mixing and loading, with the left hand the most contaminated. Urinary metabolite (paranitrophenol) levels were lowered after exposure in seven of the eight tested activities. It should be noted that the farmer subjects have been chronically exposed to different pesticide types for an average of nine years, such that even the (high) baseline levels already showed presence of paranitrophenol.

Chawla, R.P., Sharda, V.M., Joia, B.S., Karla, R.L. (1977) *A survey of residues of organochlorine insecticides in biopsy human fat samples*. Punjab Agricultural University, Ludhiana, India.

From 1976 to 1977, fifty-one 30-ml biopsy human fat samples from patients undergoing surgery were examined. All samples contained DDT residues; highest level of DDT and related compounds (DDT-R) was 31.34 ppm, averaging at 9.14 ppm. HCH residues were also found with the highest level at 30.05 ppm, averaging at 4.30 ppm. The major component of its residues was of beta-HCH (known for its accumulation behaviour), with alpha and gamma-isomers. The high HCH incidence confirms its bioconcentration in fatty tissues, while those of the isomers indicate rather recent exposure.

Coutts, H.H. (1979) Field worker exposure during pesticide application, Sittingborne Research Center, Sittingborne, United Kingdom. Paper presented at the fifth international workshop of the scientific committee on pesticides of the International Association on Occupational Health, The Hague, The Netherlands, October 9–11.

Contacts with pesticides can occur during formulation; transport to storage or application site; transfer from container to application equipment; application; field work involving contact with residues; drift of the pesticide out of the application area; disposal of the unused chemical or containers; and during cleaning and repair of application equipment. For liquid pesticide users, the main route of exposure is through the skin and not through the respiratory tract. The greatest hazard is generally not from the application itself but during the handling, mixing and filling of concentrate formulations into mixing tanks and spray equipment. Only spray drops less than 10 µm in diameter can reach the lungs; drops between 50 and 100 µm can be inhaled and impact the nasal lining. As the drop size gets smaller than 50 µm, the farther they can penetrate into the respiratory tract. Drops less than 1 µm are completely airborne and are exhaled.

Coye, M.J., Lowe, J.A., Maddy, K.T. (1986) Biological monitoring of agricultural workers exposed to pesticides: I. Cholinesterase activity determinations, California, USA. *Journal of Occupational Medicine* 28(8).

By job category, agricultural workers at particularly high risk for pesticide-related illness are primarily the mixers, loaders, applicators, and other workers who handle agricultural chemicals directly. Among field workers, seasonal workers are at greatest risk of pesticide residue exposure because they are concentrated in high-risk crops and activities. In general, the acute cholinergic effects of severe organophosphate poisoning correlate well with cholinesterase inhibition. Chronic moderate exposure results in a cumulative inhibition of the

RBC and plasma enzymes. The appearance of symptoms depends upon the rate of fall in cholinesterase activity than the absolute level of activity reached. Workers may exhibit 70 to 80 percent inhibition of both cholinesterase enzymes after several weeks of moderate exposure without manifesting cholinergic symptoms. On the other hand, a previously unexposed individual may develop symptoms after sudden exposure and a rapid drop in cholinesterase activity of less than 30 percent.

Davies, J.E. (1976) Pesticide residue hazards to farm workers. Paper presented in a workshop on pesticide residue hazards to farm workers, held by the Western Area Laboratory for Occupational Safety and Health, February 9–10.

Florida is second only to California in terms of amounts of pesticides used. In Orange County, Florida, the center of the citrus belt, there is over sixty inches of annual rainfall, a natural phenomenon which has an important bearing on the number and type of pesticide poisoning. The organophosphate pesticides in general, and parathion and phosdrin in particular, have been found most frequently causing acute systemic illness. In the five-year period 1970–75, pesticides and herbicides were listed as the cause of death of twenty-six persons in Florida. Ten deaths (35 percent) were in children under the age of ten years. Males accounted for 19 (73 percent) of the cases. In 15 (57 percent), it is known that the victim ingested the toxicant. Three victims inhaled the agent (11 percent) and two persons died from direct contact. Ten fatalities occurred in the home.

In 1975, sixty-seven pesticide poisonings were investigated and thirty-one of these were later confirmed as being due to pesticide exposure. Twenty-six of the thirty-one cases were due to exposure to organophosphate pesticides; one was due to a combination of organochlorine and organophosphate insecticides. In a study involving sequential urinary excretion of the alkyl phosphate and paranitrophenol, it was noted that in all seven cases diethyl phosphate (DEP) concentrations were greater than 0.4 ug/ml. In addition, DEP concentrations were greater than diethyl thiophosphate (DETP) concentrations in these initial urines. Both quantitatively and qualitatively, the concentrations of DEP were in striking contrast to those seen in asymptomatic workers occupationally exposed to parathion. DEP is the alkyl phosphate derived from paraoxon, which is ten times more toxic than parathion.

FDA/MPH—Food and Drug Administration/Ministry of Public Health. (1983) Report of a profile on accidents/episodes involving toxic chemicals (pesticides) in Thailand, July–December 1983.

An epidemiological study on health related hazards caused by cholinesterase inhibitor insecticides, organophosphorus (OP) and carbamates (C), was conducted from July to December 1983. Organophosphorus and carbamate insecticides reduce the level of cholinesterase in the blood of the patients. Mechanism of OP poisoning is by way of conjugation with and thus inactivating the essential cholinesterase enzyme in the body, both the so-called "pseudo" and true cholinesterase in the plasma, brain and other tissues. Organophosphorus and carbamate insecticides are the most prominent causes of poisoning, and case fatality rates are 14.9 and 12.0 percent respectively. Morbidity and mortality rates were found highest in Chantaburi, 61.8 and 11.3 percent respectively, where cultivation is the main occupation.

Hayes, W.J. Jr. (nd) Recognized and possible effects of pesticides in man. In *Toxicology of pesticides*, Williams and Wilkins Company, Baltimore, Md., USA.

The widespread use of some synthetic compounds has led to their storage in many or all persons in the general population. Compounds known to be stored include the polychlorinated biphenyls (PCBs), butylated hydroxy-toluene (BHT) and hexachlophenene. Measurable amounts of PCBs were found in 31.1 percent of 637 samples of fat from people in the general population of USA, and trace amounts (less than 1 ppm) were found in an additional 19.6 percent of the samples. PCBs were also found in all analyzed samples from Japan, in concentrations ranging from 0.30 to 1.48. Of the chlorinated insecticides, DDT and one of its metabolites, DDE, are stored in far greatest concentration. The average intake of *p,p'*-DDT and of total DDT-derived material was 0.178 and 0.280 mg/man/day respectively in 1954, but only 0.028 and 0.063 mg/man/day respectively during the period 1964–1967. Finally, the apparent rate of decrease from an average storage level of about 6 ppm of *p,p'*-DDT and about 16 ppm of total DDT-related compounds in 1955 was considerably slower than the rate of decrease from about 300 ppm observed experimentally in man.

Hisanaga, N., Takeuchi, Y., Ono, Y., Nishizaki, T., Ito, K., Kuwabara, M., Koike, Y. (1982) A case of probable chronic pesticide poisoning mainly due to organophosphate among pest control operators. *Journal of Science and Labour* 58(6).

A pest control company employed thirty men in 1978. According to eight times' data of periodic medical examination from 1973 to 1978, the reduced serum cholinesterase was found in an average of 22 percent of workers, and the abnormal findings in liver function test were found in an average of 16 percent of workers. In order to evaluate organophosphate exposure of workers in this company, the concentration of urinary metabolite of fenitrothion, *p*-nitro-*m*-cresol,

was colorimetrically determined. The average concentrations of *p*-nitro-*m*-cresol of the pest control operators were somewhat higher than that of the controls, but the differences were not statistically significant. The patients were diagnosed as having probable chronic pesticide poisoning mainly due to organophosphate.

Kurzel, R.B., Cetrulo, C.L. (1981) The effect of environmental pollutants on human reproduction, including birth defects. *Environmental Science and Technology Critical Review*, 15(6).

In 1969, it was reported that DDT, DDE, lindane, dieldrin and heptachlorepoxy were present in the cord blood (fetal) and tissues of 10 stillborn infants, in levels equal to that of adults. This confirms the transplacental transfer of these compounds, which can also reach the newborn via the breast milk. Measuring DDE levels in fetal whole blood, they found that premature infants had levels elevated three- to fourfold relative to control, term infants. Although these elevations could be explained by the absence of body fat to store the compound, which is common in pre-term infants, a causative role of chlorinated pesticides in inducing premature deliveries cannot be ruled out.

Loevinsohn, M.E. (1987) Insecticide use and increased mortality in rural central Luzon, Philippines. *The Lancet* (June 13), 1359–1362.

The study investigated mortality in several contrasting rural and urban municipalities; looked at records of diagnosed pesticide poisoning and also at other conditions that could be caused by pesticide poisoning. The study found that in the rural areas, nontraumatic mortality rates increased among males aged fifteen to fifty-four years by 27.4 percent between 1961–1971 and 1972–1984, coinciding with the increase in pesticide use. The incidence of leukaemia, possibly associated with insecticides, increased among rural men (but not women) over the 1961–1971 to 1972–1984 period. Through the years, mortality patterns for rural males peaked during August, the month of greatest insecticide use in the wet season. After double-cropping became widespread, two mortality peaks occurred: in February when insecticides were used during the dry season crop, and again in August. This analysis links an increase in mortality in Central Luzon with occupational exposure to insecticides.

Maramba, N.C. (1988) *Assessment of adequacy of protection of pesticide handlers II (A final project report)*. Guagua, Pampanga, Philippines.

Twelve volunteer farmers were divided into two groups: protected and unprotected farmers tested before and after spraying methyl parathion 50EC at a final spray concentration of 0.05 to 0.18 kg ai/ha. While there was no significant

difference in cholinesterase (ChE) levels before and after exposure in either farmers' group, there was significant red cell ChE depression in 31 percent of the sample. Farmers wearing protective clothing had significantly higher hemoglobin levels than those without. In terms of potential dermal exposure, total pesticide residue levels by anatomical locations are 37 to 200 times higher for the unprotected group. Mean levels of urinary metabolite (paranitrophenol) for both groups were higher after exposure. There was a statistically significant lowering in the after-exposure levels of paranitrophenol of the protected group, suggesting some form of protection not only from exposure but also from systemic absorption.

Maramba, N.C., Castañeda, C.P., Marquez, C.B. (1987) Assessment of adequacy of protection among pesticide handlers III. Metro Manila and San Leonardo, Nueva Ecija, Philippines. Paper presented at the workshop on Integrated pest management (IPM) and integrated nutrient management for rice, International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines.

In a three-month period, 171 workers from seven pesticide manufacturing/formulating plants, 100 certified pest applicators from 16 pest control firms and 100 rice farmers from five villages were examined using health monitoring procedures. Simultaneously, environmental evaluation was also made. Biochemical, hematologic and urinary examinations showed significant depression of red cell cholinesterase levels in 31 percent of the pesticide plants workers. Most farmers had anemia and high eosinophil count, at 38 percent and 76 percent respectively, while most applicators (41 percent) had high platelet count but low eosinophil count. Abnormal liver function was highest (90 percent) among the farmers. Pesticide plant workers' examination revealed cardio-vascular dysfunctions, mainly mild and moderate hypertension (32 percent); mild central nervous system dysfunctions (hand tremors, numbness, facial weakness) and cervical adenopathy.

Marquez, C.B., Palis, F.G., Rodriguez, V.C. (1990) Evaluation of the health effects of pesticide use among Laguna farmers. Paper presented at the workshop on environmental and health impacts of pesticide use in rice culture, International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines, March 28–30.

The study aimed at identifying the health problems of farmers; determining the extent of the problems and the factors that affect them; and at identifying potential health indicators. The health profile of the respondents (86 percent males and 14 percent females) showed that 55.35 percent had negative findings in the eye; 53.6 percent, in the cardiovascular system; and 41 percent, in the lungs.

Hyporeflexia, a very sensitive indicator of chronic organophosphate toxicity, was found in 25 percent of the subjects. Peripheral neutrality (or OPIDN-organophosphate induced delayed neurotoxicity), which manifests as neuropathy found mainly in industrial handlers, was seen in three of the 56 farmers examined. Using the Ellman method, baseline cholinesterase levels were established and used as basis for monitoring. Forty nine percent of the samples had depressed (baseline) cholinesterase levels when re-tested at the peak of spraying. Two farmers exhibited severe cholinesterase depression.

Nemery, B. (1987) The lungs as a target for the toxicity of some organophosphorus compounds, Brussels, Belgium. In Costa, L.G., C.L. Galli, and S.D. Murphy (ed.). *Toxicology of pesticides: Experimental, clinical and regulatory aspects*, NATO ASI Series, Vol. H13.

The article mainly dealt with trialkyl phosphorothioates (TP). Human relevance of TP-induced lung injury indicate that lungs are an important site for binding or metabolism of organophosphorus pesticides; exposure by inhalation may occur in occupational activities, and respiratory distress is commonly found in acute human poisoning with organophosphate insecticides, the latter being generally attributed to the effects of cholinesterase inhibition leading to bronchospasm and excessive tracheobronchial secretions, respiratory muscle paralysis and depression of the respiratory centre; organophosphate insecticide poisoning is the commonest cause of pulmonary oedema encountered in India; delayed pulmonary oedema or pneumonitis may also be observed in organophosphate poisoning.

Ngatia, J., Ngeni, A.Y. (1979) The effects of continuous exposure to organophosphorus and carbamate insecticides on cholinesterase (ChE) levels in humans. Tropical Pesticides Research Institute, Arusha, Tanzania and Lyamungu Agricultural Research Institute, Moshi, Tanzania. Paper presented at the fifth international workshop of the scientific committee on pesticides of the International Association on Occupational Health, The Hague, The Netherlands, October 9-11.

Employees from a total of six sections from the two institutes (Agricultural Entomology, Physics, Botany and Administration) were examined. These employees handled a variety of chemicals including chlorpyrifos, dimethoate, fenthion, trichlorphon, methomyl, dichlorvos, carbofuran, DNOC, 2,4-D, atrazine, oxadiazon, carbendazim and endosulfan. There was statistically significant reduction of plasma cholinesterase enzyme at the 0.025 probability level, while there was none in the whole-blood cholinesterase in all persons examined.

Rosival, L., Batora, V. (1980) Consequences for field exposure impurities in pesticide formulation, Bratislava, Czechoslovakia. Paper presented at the fifth

international workshop of the scientific committee on pesticides of the International Association on Occupational Health, The Hague, The Netherlands, October 9–11.

Marked differences in the toxicity of some insecticides could be traced to contamination with small quantities of other chemicals which may be more acutely toxic than the parent insecticide. The two main sources of impurities in technical pesticide products are: a) the starting (raw) materials for pesticide production; and b) the manufacturing technology which will include chemical reactions possibly resulting to products containing by-products. Impurities are toxicologically important in that they may have a decisive effect on the character of toxic manifestations. Organophosphorus compounds, for example, cannot avoid the presence of interfering products of side-reactions usually in magnitude more effective in inhibiting cholinesterase activity than the parent compound.

Savage, E.P. (1976) Acute pesticide poisonings. In *Pesticide residue hazards to farm workers*. Proceedings of workshop held February 9–10, 1976. Washington, D.C.: United States Government Printing Office. 256 pp.

The total of 785 general hospitals were randomly selected for this study. All hospitalized poisoning cases admitted to the hospital during the period 1971, 1972, and 1973 were reviewed. The paper covered those hospitalized cases involving farmers and agricultural workers. As noted, there were 108 observed cases involving farmers and agricultural workers, which increased from twenty-seven to forty-four in 1973. The estimated number of poisonings in farmers and agricultural workers during the three-year period was 8,241. This transcribes into a rate per 100,000 of 9.1 for the three-year study. The estimated rate per 100,000 increased from 6.7 in 1971 to 11.4 in 1973. The organophosphate group of compounds was responsible for 204 of the 289 poisoning cases as compared with twenty-seven of the observed cases being caused by chlorinated hydrocarbon insecticides, and twenty-four by carbamates, amides and related compounds.

Schafer, M.L. (1968) Pesticides in blood, Cincinnati, Ohio, USA. *Residue Review* 24.

Pesticide toxic action is manifested almost entirely through the nervous system. Prominent signs include muscle tremor, incoordination, and convulsions. Levels below that required to produce toxic effects cause vague and nonspecific symptoms like headache, blurred vision, dizziness, and nausea. A study feeding rats with radioactive dieldrin observed that it was absorbed from the GI tract and distributed throughout the body within a few hours. After oral administration, maximum concentration were reached in body organs in one to two days, the highest concentrations appearing in the fat. Some redistribution took place in



Ueda, K. (nd) Hazards of insecticides and residue problems in rice cultivation. In *The major insect pests of the rice plant*. John-Hopkins Press, Baltimore, Md., USA. 729 pp.

In a typical experiment, a woman volunteer swallowed 20 mg of parathion, that is, 0.4 mg/kg of body weight. The p-nitrophenol was abundantly excreted in urine one and three hours after ingestion, amounting to 2.8 and 5.3 mg, respectively. This converts to over 50 percent of administered parathion recovered in urine during the three hours. Contrary to the rapid loss of parathion in the body, the blood cholinesterase (ChE) level decreased gradually until the eighth to the tenth hour, when the plasma-ChE value reached nearly one-third, and the cell-ChE level, one-half of the initial level. Minor subjective complaints as uneasiness, oppression in the breast, or growling in the stomach were felt at the lowest ChE level.

The absorption of parathion in spraying was also estimated from the excretion of p-nitrophenol, the degradation product of parathion. Nine persons were sprayed with 0.05 percent solution of parathion for one and a half days under sunshine. The p-nitrophenol concentration in the subjects' urine was more than 100 ug/dl in nozzle holders. It decreased to 50 to 70 ug/dl by the next morning, but again increased to 100 to 300 ug/dl after a full morning's spraying. The total absorption of parathion was estimated as 3.5 mg/day, and varied from 3 to 5 mg according to urine volume.

Zweig, G., Gao Ru-Yu, J.M. Witt, W.J. Pependorf, and K.T. Bogen (1985) Exposure of strawberry harvesters to carbaryl, University of California-Berkeley, Calif., USA. Paper presented in a symposium on dermal exposure related to pesticide use, April 8-13.

The study, conducted in a privately-owned strawberry farm near Corvallis, Oregon, involved carbaryl applied at 2 lbs ai/acre fifteen days prior to the first day of the study, and 18 strawberry harvesters made to wear light cotton gloves (hand exposure) and cotton patch monitors fastened to their lower legs and forearms. Lower leg exposures amounted to less than four percent of total exposure; major targets were the hands and lower arms; other parts of the body received very low or nondetectable amounts of carbaryl. The right-hand exposure rates of youths ( $\leq 14$  yrs old) was lower than that in adults ( $\geq 15$  yrs old). Also, subjects weighing  $<50$  kg showed less exposure in the afternoon than adults; no other differences were found when the group was divided according to height and body surface.

An epidemiological study on health related hazards caused by cholinesterase inhibitor insecticides, organophosphorus (OP) and carbamates (C), was conducted from July to December 1983. Organophosphorus and carbamate insecticides reduce the level of cholinesterase in the blood of the patients. Mechanism of OP poisoning is by way of conjugation with and thus inactivating the essential cholinesterase enzyme in the body, both the so-called "pseudo" and true cholinesterase in the plasma, brain and other tissues. Organophosphorus and carbamate insecticides are the most prominent causes of poisoning, and case fatality rates are 14.9 and 12.0 percent respectively. Morbidity and mortality rates were found highest in Chantaburi, 61.8 and 11.3 percent respectively, where cultivation is the main occupation.

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*Impact of Pesticides on Farmer Health and the Rice Environment* covers the various aspects of pesticide use, behavior, degradation, and impacts in wetland ricefields and presents the results of surveys conducted in the Philippines and Thailand. It includes both bibliographic reviews and selected aspects of the experimental results of a research project on pesticide impacts in wetland ricefields. The first phase of the "Pesticide Impact" project was developed in the Philippines from 1989 to 1991. It was a multidisciplinary/collaborative approach involving scientists from IRRI, NRI (England), ORSTOM (France), UPLB (Philippines) who studied the effects of pesticides on the environment and on farmer's health and the economical aspects of their use.

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