Judicious and Efficient Use of Insecticides on Rice

International Rice Research Institute

PROCEEDINGS OF THE **FAO/IRRI** WORKSHOP ON

Judicious and Efficient Use of Insecticides on Rice

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FOREWORD

The Workshop on Judicious and Efficient Use of Insecticides on Rice was held at the International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines, 21 to 23 February 1983. It was jointly sponsored by the Food and Agriculture Organization of the United Nations Intercountry Programme for Integrated Pest Control in Rice in South and Southeast Asia, and IRRI.

Workshop participants reviewed the major topics affecting the impact of insecticide use on rice. The topics ranged from efficacy and economic evaluation to resistance and resurgence. The workshop gave front-line workers in Asian rice pest control programs an opportunity to interact intensively with world leaders in basic insecticide research and development. Explicit concern for safe insecticide use was expressed throughout the workshop.

Particular attention should be paid to the workshop recommendations, which were agreed upon and circulated at the close of the workshop. The recommendations are essentially the new directions that, the participants believe, insecticide technology in rice should follow. Already, they are being cited in the development plans of a number of national programs. In the future, the FAO-IPC Programme and IRRI will facilitate communication among network members to promote progress toward the goals defined in the recommendations.

I would like to thank the members of the organizing committee for their efforts in making this workshop a success: O. Mochida, chairman, J.A. Litsinger, and M.D. Pathak, all of IRRI, and P.E. Kenmore, FAO. John Lowe, coordinator of the FAO-IPC Rice Programme, was responsible for the initial planning of the workshop.

W. H. Smith, editor; Corazon V. Mendoza, assistant editor; and Berwyn A. Seelye, editorial intern, handled the editorial work on these proceedings.

M. S. Swaminathan
Director General

RECOMMENDATIONS

The escalating use of insecticides in rice-growing areas over the last two decades has not been balanced by widespread improvements in insect pest control. Undesirable consequences have included pest resurgence, multiple insecticide resistance of major pests in high-use areas, destruction of communities of natural enemies, drastic reduction of fish as a local protein source, and disturbing increases in human poisoning. All these factors contribute to lower economic returns and increased social problems for farm communities, and portray a scenario which demands a more rational approach to rice crop protection.

The role of the participants of this FAO/IRRI Workshop on Judicious and Efficient Use of Insecticides on Rice is to make recommendations aimed at

1. minimizing dangers to human health from rice crop protection;
2. minimizing environmental disruption resulting from crop protection;
3. optimizing profitability of crop protection at the farm level; and
4. stabilizing food production at high levels.

A framework for long-term stable crop protection should be based on the primary control tactics of varietal resistance, cultural controls, and biological controls. When such control tactics fail to provide adequate protection, insecticides may be applied in relation to pest populations and economic damage levels. This approach is also of paramount importance to avoid the accumulation of deleterious alleles conferring insecticide multiple resistance in populations of major rice insect pests. Insecticide management is a critical component for accomplishing these objectives.

We therefore make the following recommendations.

A. Evaluating insecticides

1. Before recommending a compound for rice production programs, the following information should be examined:
    a. Toxicity of insecticides to natural populations of major pests and beneficial insects,
    b. Biological and chemical persistence,
    c. Toxicity data on fish and other animal food sources,
    d. Mammalian toxicity data, and
    e. Evidence of resurgence in field.
2. Pesticides which are most hazardous to humans and environment should be avoided.
3. Standard methods for laboratory and field evaluation of selectivity toward beneficial insects should be developed. National and international programs should coordinate their activities in developing these methods.
4. Chemicals should be tested against above-threshold populations in single applications, as used in integrated pest control (IPC) practice by farmers.
5. Commercial mixtures of insecticides should be discouraged.
6. The use of chemicals with low human and fish toxicity and/or low cost such as botanicals, microbials, insectistatics (compounds that decimate

insect populations by suppressing growth and reproduction rather than by causing rapid mortality), pheromones. etc., should be encouraged whenever practical.

B. Using insecticide-based tactics

7. Pest and beneficial organisms monitoring should be vigorously supported for judicious use of insecticides.
8. Economic threshold levels should be determined on a crop stage and area-specific basis and should take beneficial insect populations into account.
9. Recommendations on the minimum effective and most profitable dosage should be determined for
   a. particular species and stage of pest
   b. varietal response to pest
   c. crop canopy structure
   d. kind and formulation of chemical
   e. delivery system, including realistic volumes
   f. cultural practices
10. When crop monitoring indicates that insect infestations are localized, only the area having populations above the economic threshold should be treated.
11. Efforts should be made to optimize existing application systems, including equipment, formulation, and volume.
12. More efficient practical application methods should be developed and tested under farmers' conditions.

C. Adapting insecticide-based tactics to farm conditions

13. Where locally appropriate techniques exist, training should be given to extension workers and farmers. Otherwise, such techniques should be developed. Farmers using IPC should be using the following practices:
   a. integration of insecticides with the primary tactics of IPC (varietal resistance, biological control, and cultural control);
   b. applications based on monitoring and thresholds rather than the calendar;
   c. safe handling and application, including clothing and other protection; and
   d. proper storage and disposal of chemicals and containers.
14. In making recommendations, farmers' attitudes, perception, behavior, and resources should be considered.
15. Farm-level economic analysis of recommendations should be made annually for each area.

D. Managing insecticide resistance

16. Baseline susceptibility values should be established for major pests and beneficial insects. LD_{50} values should be regularly monitored to detect resistance as early as possible.
17. Standard methods for representative sampling, collection, and determination of resistance levels among pests and beneficial insects should be developed, if not already available, and used. IRRI will coordinate this methodology development.

18. The risk of selection of resistant populations can be reduced if
    - residual and slow-release treatments are avoided,
    - treatments are not made against both larvae and adults,
    - chemicals are replaced before they fail, and
    - a sequence of alternatives based on genetics is chosen.

E. Working together (the judicious-use-of-insecticides circle of entomologists and related specialists)

19. Through a newsletter, information should be collected and exchanged regularly. The FAO Intercountry IPC Rice Programme will coordinate this newsletter.
20. Participants in this group should pursue studies determined by their local priorities and communicate about their progress. Studies could include
    - testing chemicals in onetime applications (no. 4),
    - baseline susceptibility studies (no. 6), and
    - natural enemy response to pesticides in farmers' fields (during regular surveillance activities) (no. 3, 7).

OPENING SESSION

OPENING REMARKS

Thank you very much, Dr. Swaminathan, for outlining the areas we must address at this workshop. This first joint FAO/IRRI program came about because of a number of negative factors: the lack of trained people working on the effect of insecticides on rice agroecosystems, the lack of realistic whole-system thinking about insecticides, and the lack of ideas for approaching the problem. We hope this workshop will provide a balanced view to help us design insecticide-use programs for the medium- and long-term future, specify steps to be taken to achieve these goals, and set down the ways we can help each other in this endeavor.

During the workshop, human health and safety should be paramount in our thinking as should the primary tactics of integrated control: biological, cultural, and varietal control. That insecticides are the secondary tool is not the common thinking among rice workers, who see them as the front-line weapon. This has led to resurgence, biotypes, resistance, and the need for specificity. We must examine the ways farmers use insecticides, the economics of current and alternative practices, the screening process as a target for optimization, and the role of industry in coordination with public and private agencies.

Now that some farmers and their advisers realize that insecticides are not essential for stabilized production and may be dangerous to both health and environment, we have the opportunity and responsibility to determine better ways to use these materials.

J. A. Lowe

FUTURE DIRECTION OF RESEARCH AND DEVELOPMENT OF CHEMICALS FOR INSECT PEST MANAGEMENT

S. Ishii

Although the use of organic synthetic insecticides has remarkably increased agricultural products, these chemicals have caused poisoning and environmental pollution throughout the world. Various approaches were used to develop new chemicals having more selective toxicity between insects and mammals and less damaging effects to the environment. Some new chemicals have been practical for insect pest management. However, organochlorine, organophosphorus, and carbamate insecticides are still the principal insect control chemicals. Organophosphorus and carbamate insecticides are being extensively used for rice insect control. These two classes of inexpensive insecticides combat a wide spectrum of agricultural insect pests. However, these insecticides will eventually be replaced with more selective ones.

Insecticide-resistant populations of insects are a major problem. We must stay one step ahead of insecticide-resistant pests by developing new and safer chemicals.

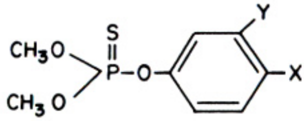
Future insect control should be directed to integrated pest management (IPM). All chemicals including conventional insecticides are being studied and applied with this in mind. Pheromones may be useful IPM chemicals. For rice insect pest control, further studies are needed on varietal resistance to pests, biological control methods, and use of chemicals in IPM.

Since World War II synthetic organic insecticides have been used extensively for insect pest control. These insecticides were so effective on noxious insects that the yields of agricultural products increased remarkably, and epidemic human and animal diseases transmitted by insects dramatically decreased. However, after extensive and repeated application of these insecticides, adverse effects such as acute and chronic poisoning, environmental pollution, disturbance of natural balance, and appearance of insecticide-resistant insects have been reported worldwide. Now we should re-evaluate how conventional insecticides are used, considering their wide spectrum and the environmental damages they can cause.

This paper discusses some approaches to developing new chemicals with more selective toxicity between insects and mammals for insect pest management, especially in rice.

Ibaraki-ken, Inasiki-gun, Kukizaki-mura, Wakaba 4-11, 300-12 Japan.

Table 1. Toxicity of methyl parathion and fenitrothion (Hollingworth et al 1967a).



Insecticide	X	Y	Toxicity			
			Housefly, topical (µg/g)		German cockroach, topical (µg/g)	White mouse, oral LD_{50} (mg/kg)
			NAIDM(S)	SC(R)		
Methyl parathion	NO_2	H	1.2	89	0.99	23
Fenitrothion	NO_2	CH_3	3.1	126	4.2	1250

CHEMICAL STRUCTURE MODIFICATION OF CONVENTIONAL INSECTICIDES

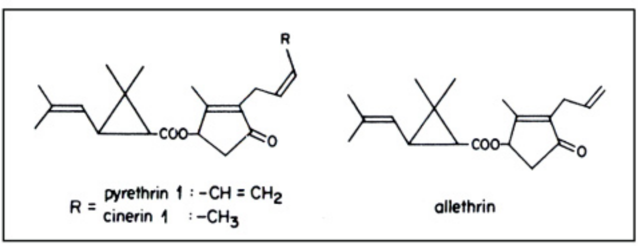
Developing new insecticides by modifying the chemical structure of conventional ones appears most practical.

This is how scientists developed fenitrothion. Fenitrothion has the chemical structure where $-CH_3$ was introduced into phenyl ring of parathion. The level of its insecticidal activity is the same as that of parathion, but mammalian toxicity is decreased to about 1/50 of parathion (Table 1). This selective toxicity between the two compounds is believed to be due mainly to the difference in inhibitory activity of cholinesterase and in the cleavage of the P-O-alkyl bond (Hollingworth et al 1967a, b).

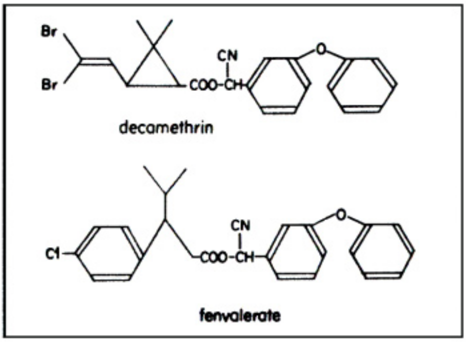
Numerous organophosphorus compounds have been synthesized and various kinds of insecticides with selective toxicity between insects and mammals have resulted. A reliable screening system is indispensable when looking for new compounds with desirable properties.

NATURAL PRODUCTS AND THEIR STRUCTURAL MODIFICATION

The first widely used synthetic pyrethroid was allethrin, an allyl homologue of cinerin I, and it is still an excellent insecticide for household insect control. Since then, a number of pyrethroids have been synthesized, and some of them show

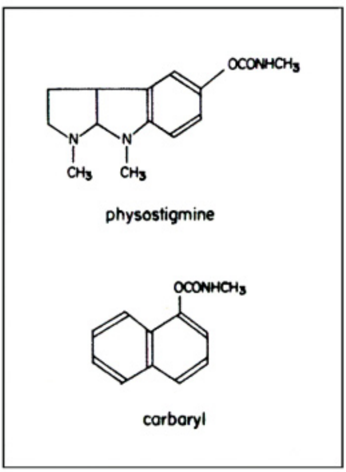


remarkable insecticidal activity at the same level as, or more than, natural pyrethrins (Elliot 1976, Elliot and Janes 1978, Katsuda 1982). Synthetic pyrethroids have been used mainly for control of household insects because of their low mammalian toxicity and harmlessness to the environment. An early defect of synthetic pyrethroids was outdoor instability, but recently developed ones show a moderate persistence even in the field. Decamethrin and fenvalerate are new types of pyrethroid — they are effective on household insects and agricultural insect pests, and have low mammalian toxicity. Fenvalerate is recommended for controlling cotton, fruits, and vegetable insect pests. However, further experiments are required because of its rather high toxicity to fish.

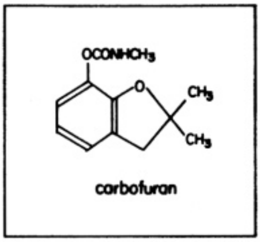


Botanical insecticides, such as neem oil, have recently gained considerable attention (Schmutterer et al 1981). Custard-apple and neem oil extracts were tested with some success on rice insect pests (Saxena et al 1981a, b; Mariappan and Saxena 1983; Schmutterer et al 1983).

Carbamate insecticides originate from physostigmine found in the calabar bean *Physostigma venosum.* Numerous structural modifications have been made to develop new insecticides from physostigmine molecules. Some carbamates are very

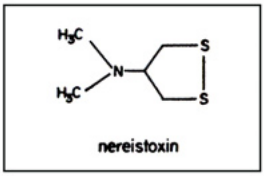


useful for controlling agricultural insect pests. Carbaryl is used predominantly for controlling planthoppers and leafhoppers in Japan. Although some kinds of carbamates show a potent insecticidal activity, they also show high mammalian toxicity. Carbofuran shows a prominent insecticidal activity and is used widely for

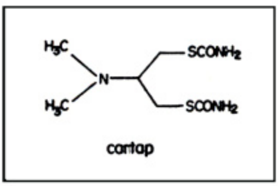


rice insect pests in tropical Asian countries. A close study of the fundamental mechanisms involved in metabolism and mode of action of carbamates in insects and mammals may lead to the development of new carbamate insecticides.

Japanese fishermen know that flies and ants die after contact with dead bodies of a marine annelid *Lumbriconersis heteropoda,* which is used as fish bait. The active principle was isolated from annelids by Nitta (1930) and named nereistoxin. The



chemical structure was determined by Hashimoto and Okaichi (1960). Various analogues were synthesized and tested for their insecticidal activity. After screening tests, cartap was selected as the most suitable candidate for a new insecticide.



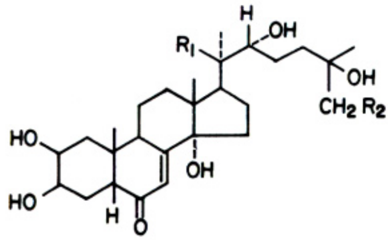
Insects treated with cartap show characteristic symptoms of excitation and paralysis. Its mode of action is mainly ganglionic blocking on the central nervous system. Cartap is now widely used for agricultural insect pests, especially the striped rice stem borer *Chilo suppressalis.*

Biologists and chemists are closely studying allomones and kairomones found in animals and plants. However, the active principles of these compounds are scarcely applicable as insect-controlling agents without structure modification.

INSECT HORMONES AND SLOW-ACTING INSECTICIDES

Hormones regulating insect metamorphosis are prothoracicotropic hormone (PTTH), molting hormone (ecdysones), and juvenile hormone (JH). The chemical structures of ecdysones and JH have been elucidated (Table 2, 3). Among insect hormones, JH and its mimics are considered to be useful for insect pest control. Some of the mimics are already commercially available. These are selectively

Table 2. Molting hormones.

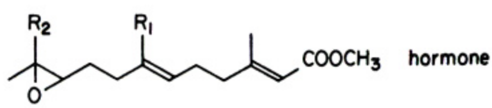


	R_1	R_2
alpha-ecdysone	H	H
20-hydroxyecdysone	OH	H
26-hydroxyecdysone	H	OH
20,26-dihydroxyecdysone	OH	OH

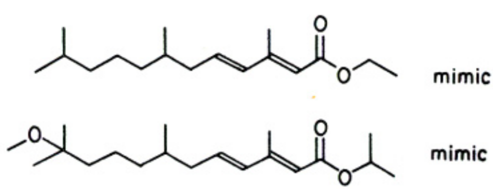
effective on insects, but have no harmful effect on mammals. JH and its mimics act gradually on insect growth and development. Moreover, their effects are conspicuously different in developmental stages of insects. Application of JH-mimics for insect control is restricted to certain species. Therefore, conventional insecticides may not be replaced by JH-mimics.

Recently, new approaches have been undertaken to develop slow-acting insecticides which have hormones and antihormones as the active agents. Dimilin, a slow-acting chemical, inhibits the biosynthesis of chitin in the insect cuticle (Oliver et

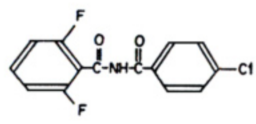
Table 3. Juvenile hormone and its mimics.



	R_1	R_2
JH-I	C_2H_5	C_2H_5
JH-II	C_2H_5	CH_3
JH-III	CH_3	CH_3



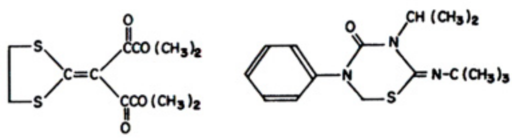
al 1976, Yu and Kuhr 1976). Insects treated with this compound are unable to molt, and die.



dimilin

Researchers found that isoprothiolane, a new fungicide that controls rice blast *Pyricularia oryzae* in Japan, also will control planthopper populations by inhibiting molting.

Buprofezin also inhibits insect molting, especially in hemipterous insects. Treated adults deposit infertile eggs. Buprofezin will soon be registered under the trade name Applaud.



isoprothiolane buprofezin

Levison (1975) proposed the new term "insectistatics," which he defined as decimating insect populations by suppressing growth and reproduction rather than causing rapid mortality. Insectistatics includes interrupting cuticle formation, inducing hormonal imbalance by extrinsic juvenoids or ecdysteroids, causing developmental disturbances with nutrient antagonists, using symbioticides, or accelerating metabolism. New bioassay methods using a wide range of test animals and long-termcareful observation are needed to screen for these types of insecticides.

PHEROMONES

During the past 20 years, scientists have identified the sex pheromones of more than 130 insect species. Because of their strong biological activity and specificity, researchers are studying ways to incorporate sex pheromones into integrated pest management (IPM) programs. However, there are many problems to solve before sex pheromones can become an integral part of IPM.

Monitoring insect population

Thousands of gypsy moth *Porthetria dispar* traps baited with disparlure, *cis*-7,8-epoxy-2-methyl octadecane, are used throughout the USA to detect new infestation and to assess moth densities in known areas. Information about moth presence obtained from pheromone traps is very useful to help determine insecticide application timing.

Table 4. Sex pheromones identified in rice insect pests.

Species	Compound	Ratio	Reference
Chilo suppressalis	(Z)- 11 -hexadecenal	4.5	Nesbitt et al (1975)
	(Z)- 13 -octadecenal	1	Ohta et al (1976)
Sesamia inferens	(Zk- 11 -hexadecenyl acetate		Nesbitt et al (1976)
Naranga aenescens	(Z)- 9-tetradecenyl acetate	1	Ando et al (1977)
	(Z)- 9-hexadecenyl acetate	1	
	(Z)- 11 -hexadecenyl acetate	4	

Sex pheromones of rice insect pests have been identified for three moth species: *Chilo suppressalis* (Nesbitt et al 1975, Ohta et al 1976), *Naranga aenescens* (Ando et al 1977), and *Sesamia inferens.* The chemical structures of the sex pheromones are in Table 4.

Beevor et al (1977) showed that the synthetic sex pheromone of *C. suppressalis,* (Z)-11-hexadecenal and (Z)-13-octadecenal, is attractive to male moths in fields when the two components are mixed in the naturally occurring ratio. Although pheromone traps are inexpensive and convenient for field use, light traps are also very effective and they attract both sexes of *C. suppressalis* as well as other rice insect pests. Pheromone traps for field monitoring of *C. suppressalis* occurrence seem applicable where light traps are unavailable.

Direct control

Mass trapping. In Japan, mass trapping of the tobacco leaf–eating armyworm, *Spodoptera litura,* was done experimentally in taro fields. The synthetic sex pheromone used was a mixture of (Z,E)-9,11-tetradecadienyl acetate and (Z,E)-9,12-tetradecadienyl acetate. The mass trapping decreased the larvae population of the next generation and suppressed taro plant damage (Yanagisawa 1979). In many trials, however, mass trapping failed to suppress insect populations. It is practically impossible to trap all the males in a field with pheromones. Remaining males will mate with numerous females. Mass trapping method appears most effective in areas of low insect population.

Disruption of mating communication. Researchers are also studying disrupting mating by permeating the atmosphere with sex pheromone or inhibitory chemicals. Gaston et al (1977) studied mating disruption of the pink bollworm moth *Pectionphora gossypiella.* They used synthetic sex pheromone, gossyplure, (Z)-7, 11–hexadecadienyl acetate, in cotton fields. The resulting disruption of premating pheromone communication between both sexes led to a population reduction of larvae infesting cotton balls.

Beevor et al (1977) showed disruption of mating of *C. suppressalis* moths with the synthetic sex pheromones and two pheromone analogues, (Z)-9-tetradecenyl formate and (Z)-11-hexadecenyl formate. All four compounds tested interfered with pheromonal communication between both sexes. Kanno et al (1978) also studied the inhibitory effects of the sex pheromones and their 12 analogues. Pheromone research suggests that mating disruption to suppress the insect population is feasible.

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DISCUSSION

METCALF (comment): One major problem with insecticide use is the high development cost in relation to potential economic threshold.

MOCHIDA (comment): This is particularly true when increasing yields are due to resistant varieties. This decreases insecticide demand and lowers profitability for manufacturers.

ISHIKURA (comment): A large part of development cost is attributable to safety testing. Broad-spectrum insecticides may provide a more economical strategy and are preferred by farmers.

KENMORE (comment): 1) Farmers' desire for broad-spectrum insecticides dates from the period before integrated pest control. When thresholds are used for specific insects, farmers are prepared to follow recommendations for specific chemicals. This is associated with a reduction in the frequency of applications from six or more to one or two per season. 2) Practical methods for economic analyses of returns from insecticide use are needed in a) preregistration screening, and b) development of recommendations. It is to be hoped that economists will provide an appropriate methodology.

METCALF. There is some confusion about the definition of pyrethroids. Not all of them have the same type of chemical structures. Can you explain?

Ishii: The definition depends partly on the chemical structure and partly on the reaction site of the compound.

Lim: Farmers prefer chemicals that give a rapid knockdown effect. What is your view of the potential use of slow-acting compounds and their likely acceptability?

Ishii: JH mimics have proved effective in Japan, but farmers' preference for immediate mortality will probably limit the use of slow-acting compounds to large organizations, such as government agencies.

Saxena: Pesticide resistance affects the economics of pesticide application. What is the effect of pesticide mixtures on resistance? Are mixtures less likely to induce resistance?

Nagata: Mixtures are not always effective in reducing the development of resistance although their use is likely to increase in association with labor shortage.

Malik (comment): Ease of application, together with cheapness and efficiency, is a major consideration in the choice of chemicals for IPC.

THE ROLE OF INSECTICIDES IN RICE INTEGRATED PEST MANAGEMENT

G. S. Lim and K. L. Heong

In the foreseeable future, insecticides will continue to supplement and complement nonchemical components in rice integrated pest management (IPM). Insecticide use will primarily relate to selectivity.

In rice IPM, insecticides can be integrated with biological control, resistant varieties, and cultural methods. Integration with moderately resistant varieties appears to be particularly promising.

Despite the flurry of research on insecticide selectivity, many farmers, particularly in the developing Asian countries, are still unaware of basic insecticide usage. Much of this relates to factors influencing farmers' decision making in pest control, information gaps, and farmers' perceptions. These are considered in relation to the role and exploitation of insecticides in rice IPM.

In 1980, an estimated $3.9 billion was spent on insecticides worldwide — $563 million (14.4%) for rice alone. The widespread increase of insecticide use in rice is largely due to convenience, simplicity, effectiveness, flexibility, and economy. Large yield increases attributed to insecticide use have been experienced under varied conditions in nearly all the rice-growing countries (Table 1).

If farmers could recover just part of the 31.5% yield loss attributed to insects on Asian farms (excluding mainland China) one skirmish in the battle against hunger could be won (Cramer 1967).

Some previously insignificant insects such as the whorl maggot, the brown planthopper (BPH), and the whitebacked planthopper (WBPH) have become economically important. The BPH has recently emerged as a major pest throughout tropical Asia. Dyck and Thomas (1979) estimated losses caused by BPH to be about $300 million in 11 countries, $100 million in Indonesia alone. Outbreaks are now more frequent and of greater magnitude (Lim 1971, Lim and Heong 1977, Lim et al 1978, Dyck and Thomas 1979, Hirao 1979). During such outbreaks, insecticides and varietal resistance provide the immediate and acceptable solutions to ward off devastating damage with near total crop losses.

Although not well understood, there is some evidence that cultural practices relevant to the modern varieties (MV) generally contribute to increased pest severity. Such practices are still on the increase. In a few countries these practices have also begun to aggravate the pest status of other insects such as the leaf folder. Considering

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Table 1. Rice yield increase resulting from insecticidal protection.

Pests[a]	Country	Insecticide used	Yield increase	Source
		Experiment stations		
Combination	Taiwan	Unspecified	17-65% (av 44%)	Tao and Yu 1967
Combination	Philippines	Wide range	Av: 2.7 t/ha (based on 67 trials from 1964-1967)	Pathak and Dyck 1973
GLH+tungro	Philippines	Unspecified	3 t/ha	Heinrichs 1978
WM+virus	Philippines	Monocrotophos	0.77 t/ha	IRRI 1977
WM+GLH+virus	Philippines	Carbofuran	3.19 t/ha	IRRI 1977
GLH+BPH	Philippines	Carbofuran	1.29 t/ha	IRRI 1977
WM+SB+GLH	Philippines	Carbofuran	1.74 t/ha	IRRI 1977
WM+SB	Philippines	Carbofuran	443 kg/ha	IRRI 1977
WM+SB	Philippines	Chlordimeform	1.71 t/ha	IRRI 1975
WM+GLH+WBPH+LF	Philippines	Carbofuran	0.66 t/ha	IRRI 1977
WM+BPH	Philippines	Carbophenothion	2.05 t/ha	IRRI 1975
WM+SB+LF+virus	Philippines	Cartap	1.18 t/ha	IRRI 1975
WM+SB+BPH+virus	Philippines	Chlordimeform+MIPC	3.14 t/ha	IRRI 1975
SB	Malaysia	Trichlorfon	718.52 kg/ha	Kimura 1965
SB	Malaysia	Diazinon	855.88 kg/ha	Lim 1972
SB	Malaysia	BHC+carbaryl	934.59 kg/ha	Lim 1972
SB	Malaysia	Fenitrothion	1350.34 kg/ha	Lim 1972
		Farmers' fields		
Combination	Philippines	Unspecified	0.5-1.0 t/ha	IRRI 1978c
WM+LR	Philippines	Carbofuran	0.57 t/ha	Litsinger et al 1980a
Combination	Sri Lanka	Unspecified	0.7 t/ha	Gunasena et al 1977
Combination	Bangladesh	Unspecified	2.6 t/ha	Ahsan and Hoque 1977

[a]BPH = brown planthopper, GLH = green leafhopper, LF = leaffolder, LR = leafroller, SB = stem borer, WBPH = whitebacked planthopper, and WM = whorl maggot.

the yield increases generated through chemical protection and the increasing severity of insect problems, need for insecticides in rice insect control will continue.

Although alternatives to chemical control have been explored, to date unaided nonchemical control methods have not been satisfactory, except for some plants bred for resistance (Pathak et al 1979, Pathak and Khush 1979) and the manipulation of biological agents in China (IRRI 1978b, Chiu 1980). There is potential for novel natural chemical methods such as sex pheromones, feeding inhibitors, and insectistatic compounds. However, they have so far proved to be severely limited in application. So, for now, barring a breakthrough, we will remain crucially dependent on conventional chemical pesticides.

Essentially, insecticides suppress insect pests to prevent crop losses. For many years after their introduction and initial spectacular successes, they have remained the major, if not the only, control strategy for many crops including rice. They essentially were used to exterminate the pests. On rice, many undesirable effects have become apparent, particularly over the last 2 decades as insecticide use gradually intensified. In the light of this, we must re-examine the insecticide role in IPM programs.

Within the frame of IPM which is the selection, integration, and implementation of pest control based on predicted economic, ecological, and sociological consequences (Bottrell 1979), the use of insecticides in rice production has shifted from indiscriminative to judicious. Insecticides should satisfy the social requirements of society as well as the personal needs of rice farmers. Because the basic premise of IPM is that a single pest control method has fewer chances of success, the fundamental role of insecticides should be supplementary or complementary.

INSECTICIDES AS A COMPONENT OF RICE IPM

Because insecticides are a component in rice IPM, they must be integrated with the other nonchemical components. The indiscriminate use of insecticides must be minimized by seeking features that relate to selectivity.

Within the IPM framework, Way (1977) placed insecticide use in three categories. First, they should be used only to avoid predictable economic damage. This means applying with the most effective techniques at the correct time and in minimum dosage. Second, insecticides should be integrated with other control methods for particular pests or pest complexes when alternative methods cannot keep pests in check. Third, socioeconomic aspects of insecticide use must be considered. The strengths or weaknesses of specific insecticide input must be identified within each management strategy. This will help provide the basis for exploiting the role of insecticides in rice IPM.

METHODS OF ACHIEVING INSECTICIDE SELECTIVITY AND ADOPTION

The basic reason for using insecticide selectively in IPM is to avoid or minimize undesirable effects of the chemical on nontarget organisms and the environment while deriving optimum pest control. Various methods for achieving selectivity in rice have been investigated. The nature of selectivity, potentials and limitations, and usage status of these methods are summarized in Table 2.

Table 2. Using insecticides selectively in rice integrated pest control.[a]

Methods of using insecticides selectively	Nature of selectivity	Remarks (potentials, limitations, etc.)	Status of usage: Experimental (+) or field observation & experience (++)	Status of usage: Practiced by farmers
I. Intrinsic selectivity				
1) *Using only insecticides which are inherently more toxic to the pests than natural enemies.* Some examples include chlorophenamidine, malathion, and BPMC which are highly toxic to green leafhopper (GLH), but least toxic to *Lycosa* spider (1,2). Also, chlordimeform and BHC are highly effective against stem borers but relatively safe to their egg parasites (3). Perthane is highly effective against brown planthopper (BPH: but least toxic to spiders, *Cyrtorhinus,* and coccinelids (4).	Inherent specificity	Most effectively utilized in national recommendations when a single pest is main target, or with specific combinations for a few pest species (5). However, there are serious limitations to exploiting intrinsic selectivity (6.7) because relatively few insecticides possessing desirable specificity are presently available. Moreover, the few that are relatively safe to natural enemies may further be restricted because of other undesirable effects such as high toxicity to fish (8,9) and inducement of pest resurgence (10,11).	+ (1, 2)	Limited (5)
II. Ecological selectivity				
1. *Timing of application* For stemborers, the best timing is after peak hatching of larvae prior to dispersion and boring. At such time, exposure is maximum with	Correct timing to avoid adverse effects on natural enemies through appropriate consideration of the distri- bution of pests, exposure of	Good understanding of the pest ecology is necessary. However, this is usually lacking, posing tremendous limitations, particularly to	+ (12) ++ (13,14) + (12) ++ (13,14)	Limited (13, 14)

high concentration of individuals and low mobility (7). For rice hispa, treating the adult stage is most effective as the eggs and larvae are normally encased within leaves (7). With BPH, application should be at peak nymphal density in each generation (about when 3d-instar nymphs dominate) (12).	latter to treatment, and mobility of both pests and natural enemies. Proper timing could also result in effective control, thus avoiding further applications and excessive use of chemicals as for BPH in Japan (13) and Korea (14).	farmers. Though such timing may be applicable in temperate conditions, it is especially difficult in the tropics where overlapping of broods is common and discrete generations are absent.		
2. *Partial or spot treatment.*				
a. *Seedbed treatment.* An example is using BPMC or carbofuran against GLH and tungro infection (15)	Succulent seedlings are usually more preferred by some pests, particularly GLH. Since seedbeds are generally small and natural enemies less signifcant, insecticide applications are not only minimal and safer, but also economical (7). Overall pollution is also less while adverse effects on fish are almost nonexistent.	Because pest buildups are usually not obvious, most farmers do not practice seedbed treatment. In any case, this is only applicable in certain situations.	+ (15)	Limited (7, 15)
b. *Treating border areas of transplanted fields.* This is used in the control of rice water weevils (7, 16).	Highest densities of some pests (e.g. rice water weevils, stem borers) have frequently been observed to occur in the peripheral areas of a field. Treatment of only these areas has advantages similar to that in II.2.a	Only occasionally practiced by farmers because many affected fields may be missed due to irregular field checking that is governed largely by convenience. This method is applicable to only a limited number of pest species.	+ (7,16)	Limited

Continued on next page

Table 2 continued

Methods of using insecticides selectively	Nature of selectivity	Remarks (potentials, limitations, etc.)	Status of usage: Experimental (+) or field observation & experience (++)	Status of usage: Practiced by farmers
c. *Spot treatment of attacked plants or parts of plants.* This treatment is done on plants showing early signs of deadhearts (17) or in directing sprays onto basal portions heavily infested by BPH during initial buildups (4,7,14,18,19,20,21). Over larger areas swaths 2 m apart are sprayed (7).	Such treatments prevent spread of the buildups, minimizing excessive insecticide applications and hence the adverse environmental impacts.	This technique requires constant surveillance by a farmer right inside his fields. Because of this demand, many farmers still do not practice spot treatment satisfactorily.	+ (17)	Moderately
3. Treatment of trap crop. Peripheral planting of susceptible variety are set up and treated to confine infestations of BPH (21, 22).	Since such treatments are confined to restricted areas, excessive insecticide usage is avoided, minimizing undesirable side effects.	To implement this, special extra efforts are needed. Moreover, farmers believe that trap crops may cause eventual and larger buildups in the main field because of the nearby source.	+ (22)	Limited (48)
4. Treatment of weed hosts. Some practices are spraying of wild grasses and weeds to prevent armyworms and cutworms from building up and moving into the rice crop after consuming the grasses and weeds (3, 7).	These peripheral treatments outside the crop do not pose any hazard to fish and beneficial arthropods active within the crop area.	Such treatments can be very costly as alternative host weeds are sometimes quite extensive. Moreover, except for a few advanced farmers, most could not conceive of the need to treat areas outside the crop.	++ (3 ,7)	Limited (23, 24)

Another example is the destruction of alternative host weeds of tungro with paraquat to reduce viral inoculum source (23). In Sekincan, paraquat is applied along sides of irrigation canals to kill off weeds harboring pests (particularly rats) (24).				
5. *Soil and water application.* When applied to the paddy water, a number of chemicals *viz:* carbofuran, diazinon, acephate, chlordimeform (4), bendicarb (18) and cartap (25), have been found effective in controlling pests. Also found effective against a variety of pests were applications to the root zone of especially formulated insecticides such as lozenges (4, 7), mudballs (4), short paper straws (12), band injection of slurry and in liquid (4), gelatin capsule (4, 26, 27, 28).	These applications are considered selective in that natural enemies of pest species are most affected by feeding on plants sprayed over with insecticides. (*Note:* Selectivity is not always achieved as beneficial species feeding or ovipositing on plants protected through soil and water applications such as fumigation may also be affected to a limited extent indirectly. There could also be food chain effects (2) or pest resurgences (10, 11, 14, 21, 29, 30, 31)	For application through irrigation water, a major limitation is the unavailability of good water control in most farms. With root-zone techniques, much effort is needed to manually introduce the insecticides. Where an implement is employed, high cost may pose a limitation. For soil incorporation, some spray applications on the crop may still be necessary at later stages.	+ (4, 7, 52)	Limited (52)

Continued on next page

Table 2 continued

Methods of using insecticides selectively	Nature of selectivity	Remarks (potentials, limitations, etc.)	Status of usage: Experimental (+) or field observation & experience (++)	Status of usage: Practiced by farmers
Incorporation of granules at the last harrowing constitutes a practical root-zone application method. This soil incorporation technique (with carbofuran in particular) is effective against stem borers and whorl maggot (18), BPH and GLH (25).		This technique has tremendous potentials as it readily controls a number of pests in the early crop stages, has adequate protective period, and has minimal side effects to nontarget organisms and the environment. Most important, it is simple and can be easily carried out by farmers.		
In upland rice, placement of carbofuran or lindane + MTMC (21) in furrows 2-3 cm below the seed provided some control of BPH.				
6. *Seed and seedling root-coat treatment.*				
Soaking of rice seeds or seedlings in insecticide solution prior to transplanting to provide early protection against whorl maggot and GLH has been investigated (7, 12, 18). Some effective chemicals are carbaryl, carbofuran, diazinon, lindane, MIPC, and	These techniques reduce the necessity of foliar sprays with wide-spectrum insecticides which have many undesirable effects (7). Runoff due to rain that may increase pollution is also minimized. Particularly in seed treatment, phytotoxicity can be reduced by the use of a sticker in conjuction with a	These techniques blend well with the advantages of systemic chemicals. With incorporation of a sticker such as methyl cellulose or gelatin, residual activity is further improved. The addition of a mineral soil conditioner, such as perlite, could extend the protection period by coating	+ (7, 12, 18, 32, 52)	Limited

propoxur (12, 18).	powder dust formulation and activated charcoal (7).	the seedling roots and acting as a reservoir for further uptake of systemic insecticides after transplanting (18, 32).		
III. Formulation & application selectivity				
1. *Granular formulation.* Granular insecticides have been found effective and used on a wide range of pests. Examples are BHC, carbofuran, diazinon, and endosulfan against stem borers (12, 33, 34, 35, 36); BPMC, carbaryl, diazinon, gamma-BHC, MIPC, and triazophos against leaf- and plant-hoppers (12, 30, 31, 35, 36, 37, 38); and carbofuran diazinon, and ethoprop against whorl maggot (18).	Since applications are made directly onto the soil or water only, granular insecticides are generally less toxic to the operator than sprays or dusts (7). Contamination is usually less because granules are less subject to degradation by sun-light, high temperatures, or wash-off by rain. Hazardous drifts are also markedly reduced due to impregnation of the toxicant on inert or organic carrier particles 5-100 µm in diameter. (*Note:* Although less toxic to natural enemies than foliar applications (39), granules can still result in food chain effects (2) and contamination of water running from treated areas (7)).	An advantage is that costly equipment is not required; application is easy and simple. Placement of the insecticide in the immediate crop area is more effective. Since it is impregnated on a sorptive carrier, there is sustained release of the toxicant. How-ever, granular insecticides are normally formulated at lower concentrations; therefore, the applied quantity is greater, and costs are higher.	+ (2, 12, 18, 30, 31, 34, 35, 36, 37, 38, 39)	Extensive (40, 41, 42)
2. *Ultralow volume (ULV) sprays and controlled droplet application (CDA).* Applications using the Micron ULVA and Turbair	Compared to high volume spraying, there is relatively little runoff with ULV application, hence side effects associated with pollution are	Since only small quantities of solvent, and not excessive amounts of water are used in ULV spraying (1-10 liters/ha) and CDA (5-20 liters/ha), there	+ (43, 44, 52)	Limited (52)

Continued on next page

Table 2 continued

Methods of using insecticides selectively	Nature of selectivity	Remarks (potentials, limitations, etc.)	Status of usage: Experimental (+) or field observation & experience (++)	Status of usage: Practiced by farmers
have provided effective control of both stemborers and leaffolders (43). There is indication that the techniques have considerable potential for use against rice pests (44).	less. With CDA which is "using the minimum volume of liquid compatible with economic control" (45), droplet sizes can be controlled precisely (46) for a specific situation. As such, unnecessary drift can be avoided, and contamination of nontarget areas reduced. (It is also noted that ULV and CDA techniques may not provide the selectivity needed of IPC since the improved effectiveness of these techniques against pests would suggest that they will also be equally efficient in destroying natural enemies (7). Evidently, further investigations are needed on their ecological impacts.)	is economic advantage of savings in time and labor (7). Residues are also more persistent (47), hence protective period is longer. Presently, applicators are available to small farmers at relatively low cost and are light and easy to use. The main limitation is the high running cost of batteries and the poor range of insecticides formulated for these applicators.		
3. *Conventional foliar sprays.* Foliar sprays with conventional insecticides have been used quite effectively on a	The selectivity to be derived depends on the inherent specificity of the chemical	The main limitations include the need to use large amounts of water, excessive runoff,		Extensive (7, 21, 40, 41, 42, 51)

number of pests: rice bugs, leaf- and planthoppers, leaf-folders and leafrollers, whorl maggot, and stem borers. Some commonly used insecticides are acephate, BHC, BPMC, carbaryl, chlordimeform, endosulfan, ethion, metalkamate, monocrotophos, MTMC, and propoxur (4, 12, 14, 18, 25, 34, 49).	and on the manner of usage, of which much is related to the different techniques discussed above. The formulation used is also critical, e.g. emulsions of chlorophenamidine is 12 times as toxic to spiders as the wettable powder formulation (1, 2, 7).	and inconsistency in providing good control. However, effective rates (1000-1400 liters/ha) used in earlier periods can now be reduced to 100-400 liters/ha (7, 50). An important advantage is the availability of a wide range of chemicals. The applicators needed to deliver them are relatively cheap, readily available, easy to maintain and use. The most common is the small conventional high-volume hand sprayers (7, 51).

[a] Numbers in parentheses stand for the following sources: 1 (Kiritani 1972), 2 (Kiritani 1976), 3 (Lim and Heong 1976), 4 (IRRI 1975), 5 (Magallona and Feuer 1976), 6 (Way 1977), 7 (FAO 1979), 8 (Yunus and Lim 1971), 9 (Supaad et al 1972). 10 (Chelliah and Heinrichs 1980), 11 (Chelliah et a1 1980), 12 (IRRI 1973), 13 (Nagata et al 1973), 14 (Heinrichs 1979), 15 (Chang, P. M. 1982, pers. comm.), 16 (Lange et al 1970), 17 (Lim 1970), 18 (IRRI 1978a), 19 (Heong 1975), 20 (Lim et al 1978), 21 (Heinrichs et al 1979), 22 (Saxena 1978), 23 (Dept. Agric. 1982), 24 (Authors' personal encounter with farmers), 25 (IRRI 1979) 26 (Pathak et al 1974), 27 (Choi et a1 1975). 28 (Sama and van Halteran 1976), 29 (IRRI 1971), 30 (IRRI 1974), 31 (IRRI 1977), 32 (Seiber et al 1977), 33 (Ministry of Agriculture and Cooperatives 1967), 34 (Lim 1971), 35 (Pathak et al 1967), 36 (Bae and Pathak 1969), 37 (Toyoda 1970), 38 (Koyama 1971), 39 (Fernando 1970), 40 (Heong 1982), 41 (Litsinger et a1 1980a), 42 (Litsinger et al 1980b), 43 (Lim et al 1977), 44 (Pickin et al 1981), 45 (Matthews 1977), 46 (Matthews 1979), 47 (Maas 1971), 48 (IRRI 1978b), 49 (IRRI 1968), 50 (Sacay et al 1971), 51 (Lim et al 1982), 52 (Chiu 1980).

Of the numerous methods suggested for using insecticides selectively, intrinsic selectivity has been recognized to be quite limited. An ideal insecticide which destroys the target pest with little or no side effects on other animals or plants is rare (Way 1977). For instance, carbofuran is highly effective against some key pest species besides being safe to nontarget organisms such as natural enemies, fish, bees, and birds when properly applied through in-furrow and band applications (Estores et al 1980). It is readily biodegradable and does not concentrate in food chains (Metcalf and Sangha 1971). However, it can cause BPH resurgence (Heinrichs 1979). For the few insecticides with some levels of specificity, the occurrence of a large pest complex can still contribute to their limited use by farmers (Table 2).

Way (1977) pointed out that the economics of producing selective insecticides is highly questionable except for certain major pests. The most realistic goal is to learn how to use relatively broad-spectrum insecticides in ways that will make them selective. There are numerous possibilities which relate to ecological selectivity and formulation and application selectivity. It is evident (Table 2) that nearly all techniques suggested to date are still in the experimental stage. Some that are being practiced by farmers to a limited extent are application timing, seedbed treatments, borders for transplanted fields, trap crop and weed hosts, soil and water applications, seed and seedling root-coat treatments, root zone application, ULV sprays, and controlled droplet application.

Granular formulation and spot treatment of attacked plants or plant parts appear to be more widely practiced. Even so, the adoption varies greatly in different localities, both within and among countries.

Although conventional foliar sprays are most common, this technique often fails to achieve the desired selectivity. This is because of its dependence on the inherent specificity of the chemical and the application method which are closely related to limitations of other methods (Table 2).

Unfortunately, although insecticide use has achieved increased crop yields, it has not been particularly successful from an IPM standpoint. The reasons are immediately evident in Table 2.

Except for a few instances, most of the techniques have not been adequately investigated so that sound recommendation can be made. Many findings have been inconclusive. Researchers should stop hiding behind the phrase "more studies are needed" (Litsinger et al 1980a).

Another major limiting factor is poor extension programs in many countries. Extension personnel are generally in close contact with farmers and their practical problems. They are looked to for advice. Of critical importance is their communication role of getting information about selective use of insecticides to farmers.

Generally, the extension services are currently inadequate for many rice growing areas, especially in Southeast Asia (Glass et al 1971). Many extension personnel are unaware of IPM techniques and need training.

Rice farmers themselves must be considered. Abysmally little is known about the farmers' needs and their perceptions of such technology. Research scientists, while developing relevant IPM technology for rice, must be in empathy with the rice farmer — the ultimate consumer of any developed technology.

INTEGRATION OF INSECTICIDES WITH OTHER CONTROL METHODS

In rice IPM, insecticides can be integrated with biological control, resistant cultivars, and cultural methods.

Insecticides and biological control

To date, successes of classical biological control have been few. Numerous failures have been reported (Nickel 1964, 1967; Rao 1965; Yasumatsu 1967; Yasumatsu and Tom 1968; Lim 1974). However, the use of biocontrol methods, when integrated with insecticides, can be highly effective. For instance, in South China *Trichogramma* parasites are being mass-reared and released to control leaffolders. Insecticides are used only when necessary and usually for controlling other pests such as stem borers, thrips, and planthoppers (Chiu 1980). *Bacillus thuringiensis* has also been integrated with low dosages of insecticides (0.1-0.2 of the normal strength) to provide effective control of lepidopterous pests in Kwangtung Province (Chiu 1980).

Insecticides and resistant cultivars

Insecticides are very complementary to resistant varieties. Often, rice varieties are resistant to a few insect species and need insecticidal control for others. For instance, in the Philippines IR26 is resistant to BPH, but insecticides protect it against whorl maggot (Heinrichs et al 1979).

On moderately resistant varieties, developing insects may be less vigorous, smaller, and less fecund, and may succumb more readily to insecticidal treatments. For example, stem borer infestations on varieties receiving only one or two insecticidal treatments were similar or lower than those observed on susceptible varieties receiving twice the amount (Saxena 1980).

Biotype selection is a major problem in the use of resistant varieties for BPH control. However, Panda and Heinrichs (1982) have identified rice varieties with no major genes for BPH resistance (IR46, Kencana, Triveni, and Utri Rajapan). Though only moderately resistant, they are stable to BPH stress. Such tolerant varieties, when supplemented by insecticides on a need basis, can be expected to have an important role in BPH management.

Insecticides and cultural methods

There have been classic successes in cultural control of rice insect pests in the yellow stem borer in Japan and the white stem borer in Java. Close planting in rice not only contributes to rapid increases of pests such as BPH (Oka 1979), but it also prevents foliar sprays from reaching target pests under the canopy. However, wide spacing can significantly reduce yields. Similarly, increased inputs of fertilizer found to increase pest problems (Dyck et al 1979, Oka 1979, Heinrichs et al 1979) can also increase yields. If IPM programs are to be successful, appropriate integration of good cultural practices with control methods such as resistant varieties and insecticides is necessary.

Insecticides can play a significant role in complementing cultural practices. For example, in BPH control, the effect of water drainage is enhanced by insecticidal applications. For others, the spraying of susceptible “trap” crops has also proved helpful (IRRI 1978b). In any case, because a cultural practice may have opposing effects on different pests (Kiritani 1972, Lim and Heong 1976), insecticides could be integrated in such circumstances. The cultural practice could be used to control the key pests while chemicals control less important species.

SOCIOECONOMIC CONSIDERATIONS

Despite the flurry of sophisticated research into insecticide specificity and selective techniques, there are still many Asian rice farmers who are not aware of the basics of insecticides. Although most know of the values of insecticides, they use them infrequently, often badly timed and vastly underdosed (Litsinger et al 1980b, Heong 1982b). Ignorance of the pest agents is also widespread partly due to superstition and inadequate knowledge (Afifuddin 1978, Litsinger et al 1980b).

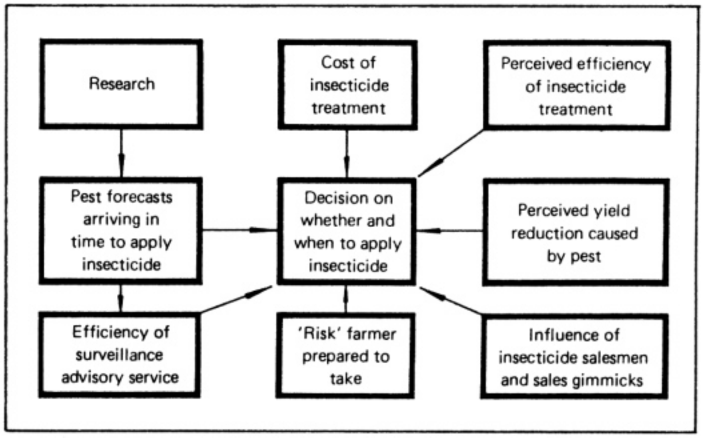
In general, there is a wide information gap (Norton and Mumford 1982) that can arise at several points. For instance, information may be lost during dissemination or, upon reaching the farmer, it may be in a form he cannot understand.

Most rice farmers are hindered by a lack of information. Among the numerous factors and processes governing decision making (Fig. 1), only the cost of treatment can be accurately quantified (Way 1977). Other factors, such as treatment efficiency and expected yields, depend mostly on farmers’ perceptions.

In bridging the information gap, the pest surveillance and advisory service is vital. This service monitors pest incidences and advises farmers if insecticides are needed. Authorities involved often use a decision criterion based on mean pest population trends or predetermined thresholds (Heong 1983). However, the thresholds based on the economic threshold (ET) concept (Stern et al 1959) are never totally accurate (Reynolds 1978) and in practice are frequently limited by unavoidably large errors, especially when decisions must be made early (Way 1973). It is also evident that practical application of this concept in real-life pest control is extremely difficult (Norgaard 1976, Way 1982). Although ETs will continue to be useful in preventing overuse of insecticides, they normally constitute only part of the criteria needed to decide whether control steps are needed. Working “guesstimates,” which are developed and modified with experience, will often suffice (Norton and Mumford 1982, Ooi 1982). Farmers tend to choose the method which best meets their objectives under the circumstances. Profit maximization is a secondary concern (Norton 1976, Mumford 1981, Norton and Mumford 1982).

For improving information flow to the farm level, the advice must be acceptable to farmers and delivered through appropriate channels. For instance, pest surveillance decisions are transmitted to Malaysian farmers over the radio and in prayer houses and community centers (Ooi 1982). Recently, colored boards containing key information placed in the rice fields have been effective.

In general, as the information gap becomes wider the perceptions may become poorer. The importance of understanding farmers’ perceptions is illustrated by constructing a working scenario. This scenario was synthesized from the limited on-farm studies conducted in lndonesia (Prasadja and Ruhendi 1980), Malaysia



1. Factors and processes influencing a farmer's decision-making on whether and when to apply an insecticide (adapted from Way 1977).

(Heong 1982b), and the Philippines (Litsinger 1981). It may also be applicable to most other developing Asian countries.

Usually a farmer will apply insecticides when his crops are being damaged by pests. He often perceives a chemical as a medicine which is expected to provide an immediate cure for a plant ailment. However, by the time damage is observed, such as whiteheads, it is often too late for insecticide application to do any good. Often, a farmer is unaware of the damage cause. He may apply an insecticide to plants suffering from bacterial attack or fertilizer deficiency. An agricultural technician may advise him to use ETs, but these are generally expressed in unfamiliar terms such as percentages, units/m^2, etc. Also monitoring techniques are too complex and require frequent farm visits. The farmer often finds the dilution procedure for insecticides difficult to understand, especially if some unfamiliar measurements are used. So, using his own judgment, coupled with a limited budget, he tends to underdose. He does not realize that low dosages do not offer plant protection and may still be detrimental to natural enemies. The farmer is confronted with too many brands, each with claimed effectiveness. Full of uncertainty, he tends to go for the cheaper brands or ones advertised most.

This scenario clearly points out a farmer's predicament. It shows the immense task that research and extension personnel have in trying to translate the IPM philosophy into practical realities. Without farmer understanding, insecticide selectivity research, no matter how extensive, is unlikely to be easily utilized or fully exploited.

CONCLUSIONS

We cannot emphasize too strongly that, in most IPM programs, chemicals area key component. They are the most powerful tool available and are reliable for emergency action when rice insect populations approach or exceed ET levels. With such versatility, they may be regarded as the "heart and core" of IPM. When used with sound ecological principles, insecticides can be dependable and valuable. The question is how can they be used with minimum undesirable side effects and complications?

There is much more to chemical control than simply applying them. They should be used primarily as a stop-gap or fire-fighting tool. Sound bio-environmental controls should be the front line of defense. In rice IPM, chemical users must seek to maximize the advantages and minimize the disadvantages. Remember that chemical application represents purposeful environmental contamination, and can be justified only when benefit-risk ratios are clearly tilted in favor of insecticide use. Yield increase alone with no subsequent increase in profit is obviously inadequate. More subtle, however, are the difficult to measure hidden costs such as the adverse environmental effects. Such effects, particularly on nontarget organisms, must be determined. Only then can truly selective methods be effectively devised.

The eventual extent of insecticides' role in rice IPM will be governed by non-chemical aspects, in particular the socioeconomic facet of the rice farmer. If the new IPM technology is to be successfully delivered to him, he must understand the recommendation. New methods must be compatible with farmers' resources and management capabilities as well as with overall crop production technology. The technique must work as well as present chemically based methods and be acceptable as a "good buy" for the farmer. This may seem formidable, but there can be no compromises. These are key elements of using insecticides in relation to real need, and are absolutely essential to realizing the role of insecticides in rice IPM.

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DISCUSSION

ISHIKURA: How is your information disseminated to farmers? In Japan, teams of farmers apply insecticides and the information is passed to those groups.

LIM: Action is taken by individual farmers. Blocks are surveyed and information is posted. Community organizations also exist, which disseminate recommendations developed at the national level.

ISHII: You said no problems of human toxicity arose with carbofuran. Is this really the case?

LIM: There were some early hospitalizations because of the presence of dust in the formulation, which presented a toxic hazard. The company changed the formulation and there was no further problem.

METCALF (comment): In the US, dosages on labels have been found to be 2-5 times higher than the most desirable rate for IPC. Natural-enemy mortality must also be taken into account.

THE ECONOMICS OF INSECT CONTROL ON RICE IN THE PHILIPPINES

R. W. Herdt, L. L. Castillo, and S. K. Jayasuriya

It is well established that insects cause considerable losses of rice yield. Two ways of avoiding such losses are the use of insecticides and the planting of resistant varieties. Insecticides can be effective, but they are expensive, particularly at the high rates of application required for complete protection. Prolonged exposure to insecticides also results in a buildup of resistance in the insect population, subsequently leading to more difficult control problems. Resistant varieties may also have serious problems, so a combination of methods has come to be preferred.

The development of the economic threshold concept, wherein insecticides are applied only when insect populations exceed predetermined levels, has led to substantial economy in insect control and increased net returns to farmers. The use of economic thresholds with resistant varieties to minimize the use of insecticides while protecting the crop has come to be recognized (at least to laymen such as the agricultural economists) as integrated pest management (IPM). But the practical problem of developing recommendable IPM practices is still a challenge. We hope to address that challenge in this paper.

Specifically, we attempt to answer several questions related to the economics of insect control on rice in the Philippines:

1. How large are the rice yield losses from insect damage?
2. How economically profitable is it to prevent yield losses with insecticides and or resistant varieties?
3. How can the risk-preventing nature of insecticide application be measured?
4. What kind of information is required to make practical recommendations to farmers?

Accurate estimates of insect damage and of the economics of preventing insect damage are difficult to make because insect populations vary from year to year and season to season.

Given the importance of variability in insect pressure, valid indicators of yield losses must be based on large samples of observations representative of some particular area. Moreover, data should be analyzed as a sample from a population: no observation should be considered as separate or unrelated.

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RICE YIELD LOSS DUE TO INSECTS IN THE PHILIPPINES

Different types of experiments could be conducted to measure yield losses. A limited amount of data that compare protected and unprotected plots at research stations and in farmers' fields is available. Additional data that compare the yield with farmer's present practices to the yield with complete protection in farmers' fields are available. Each data type gives a slightly different measure of yield loss (Fig. 1).

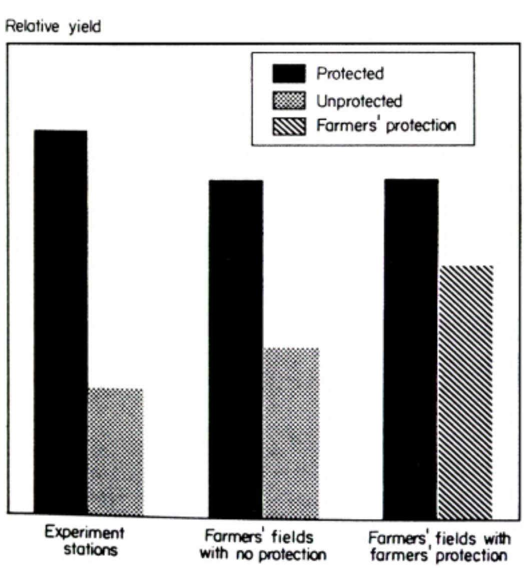
The first data set is from yield loss experiments conducted at IRRI and at the BPI research stations at Maligaya, Bicol, and Visayas, with insect-resistant and non-resistant rice varieties. Data from experiment stations may overstate the yield losses expected from insect damage to farmers' rice because insect population levels may be higher at experiment stations than in farmers' fields. These high levels may be due to the presence of rice in all stages of growth and to the experimental use of insect-susceptible varieties that provide a reservoir of insects. The first set of experiments is therefore expected to show a very high "protected" yield and a big difference between that and the lower "unprotected" yield than in farmers' field experiments (Fig. 1).

The second data set is from farmers' field experiments comparing yields with maximum protection to yields with no protection. The high yields in this situation are hypothesized to be lower than at the experiment station, but the yields on the unprotected plots might well be higher than yields on unprotected plots at the experiment station because of the reasons discussed above.

A final set of data compares complete protection with farmers' level of protection. One might expect the loss in this case to be the smallest if farmers' protection practices are somewhat better than the complete lack of protection.

Yield losses at experiment stations

Between 1972 and 1974, IRRI cooperated with the BPI in conducting a series of



1. Hypothesized relative yields with and without insect protection under specified conditions.

Table 1. Insecticide treatments and resulting yields with varying levels of insect protection in experiments at 4 research stations, Philippines, 1972-74 dry seasons.

Treatment	Nonresistant rices [a]		Resistant rices [b]	
	Average yield (t/ha)	Observations (no.)	Average yield (t/ha)	Observations (no.)
No protection	3.6	14	4.2	21
Economic threshold [c]	4.1	10	3.8	17
Next higher [d]	4.2	16	4.9	30
Maximum protection	5.7	6	6.1	11

[a] IR8, IR22, BE-3, IR1561-22, C4-63. [b] IR20, IR26, IR1514AE597. [c] One application, usually a sprayable insecticide. [d] Two applications, usually a sprayable insecticide.

experiments at four rice research stations in different parts of the Philippines. The varieties grown had varying levels of insect resistance. The data from these trials can be used to indicate the yield losses to be expected under experiment station conditions.

The trials were designed to test a series of insecticide levels from zero to maximum protection. However, the exact timing and number of applications, as well as the insecticides used, varied across years and locations. This created some problems in using the data to get a representative measure of economic return. It was decided. therefore, to pool the data based solely on the number of applications. Pooling resulted in varied numbers of observations for each application level, but it seems to be the best practical solution.

Table 1 shows the average yields pooled across the 4 stations and 3 years, and across varieties within a type.

The data show yield losses of 2.1 t/ha on nonresistant rices and 1.9 t/ha on resistant rices. The resistant rices averaged 0.3 t higher yields per hectare and had higher yields at all insecticide levels. All treatments varied considerably because of the variability in growing conditions across locations and years.

Yield losses in farmers' fields

Since 1976 IRRI has conducted insect control experiments for different purposes in farmers' fields in five provinces of the Philippines: Iloilo, Pangasinan, Laguna, Nueva Ecija, and Cagayan. Tables 2 and 3 present the yield data for those locations. The results for Laguna and Cagayan are classified into those for resistant and nonresistant varieties; only resistant varieties were grown in Iloilo, Pangasinan, and Nueva Ecija.

Yield losses to insects in the first crop in Pangasinan were small over this period; maximum protection saved about 100 kg/ha on the average during the wet season — less than 2% of the unprotected crop was lost to insects. For the second crop, losses were 500 kg/ha, or 19% of the fully protected crop yields. In Iloilo insect damage was higher, particularly in the second crop where more than 30% yield losses were recorded. (In the later years, the maximum protection treatments included soil incorporated carbofuran. Due to its yield stimulant effect, these yield loss figures

Table 2. Rice yield obtained from experiments in farmers' fields to test insect control techniques on insect-resistant varieties, 1976-81.[a]

	Wet season			Dry season		
	Pangasinan	Iloilo	Nueva Ecija	Pangasinan	Iloilo	Nueva Ecija
Observations (no.)	37	35	7	20	15	16
			Yield (t/ha)			
No protection (NP)	4.3	3.9	4.4	2.2	2.1	6.5
Economic threshold (ET)	4.4	4.3	5.3	2.6	3.2	5.8
Next higher (NH)	4.5	4.6	5.2	2.1	3.2	5.4
Maximum protection (MP)	4.5	4.1	5.7	3.8	4.1	6.2
Yield loss (MP-NP)	0.2	0.8	1.3	1.6	1.4	–0.3

[a]Data provided by the IRRI Entomology Department.

may overstate the actual damage due to insects.) The results from Nueva Ecija indicate yield losses of 1,300 kg/ha in the wet season but an average of 300 kg/ha more yield was obtained on the untreated plot than on the maximally protected plot in the dry season.

The advantages of planting varieties with multiple insect resistance are shown in the yield loss figures from Laguna (Table 3). Nonresistant varieties average twice as much reduction in yield as resistant varieties both in the wet and dry seasons. In Cagayan yield losses were about 0.5 t/ha in both seasons and on both resistant and nonresistant rices. Because yields were much lower in the dry season, the percentage loss was much greater for this season.

Difference between farmers' and maximum protection

Since 1974 IRRI has conducted a series of experiments to identify the constraints to high yields that could be attributed to various manageable factors. The contribution of each factor to the total yield gap was defined as the main effect in factorial design

Table 3. Rice yield obtained from experiments testing various insect control technologies, 1980-81.[a]

	Resistant rices				Nonresistant rices			
	Wet season		Dry season		Wet season		Dry season	
	Laguna	Cagayan	Laguna	Cagayan	Laguna	Cagayan	Laguna	Cagayan
Observations (no.)	8	14	8	2	11	4	8	4
				Yield	*(t/ha)*			
No protection (NP)	3.4	2.2	4.9	0.9	2.7	2.6	3.1	0.8
Economic threshold (ET)	3.9	2.2	5.5	1.3	4.3	3.4	4.3	1.0
Next higher (NH)	5.2	2.6	5.1	1.1	3.4	3.2	3.7	1.0
Maximum protection (MP)	4.2	2.7	5.7	1.6	4.3	3.2	4.7	1.3
Yield loss (MP – NP)	0.8	0.5	0.8	0.6	1.6	0.6	1.7	0.5

[a]Data provided by IRRI Entomology Department.

Table 4. Farmers' yields, high yields, and the contribution of three tested factors to the yield gap in constraints experiments on rice farms in the Philippines, 1973-79.[a]

Trials (no.)	Province	Yield (t/ha)			Contribution (t/ha) of		
		Farmers' inputs	High inputs	Gap	Insect control	Fertilizer	Weed control
				Wet season trials			
57	Laguna	3.6	5.3	1.6	0.8	0.6	0.3
78	Nueva Ecija	3.9	4.8	0.9	0.5	0.4	0.1
41	Camarines Sur	3.9	4.7	0.8	0.1	0.2	0.1
38	Iloilo	3.9	5.2	1.3	0.5	0.7	0.3
220	All sites	3.8	5.0	1.1	0.5	0.5	0.3
				Dry season trials			
57	Laguna	4.4	6.5	2.1	1.0	0.4	0.2
60	Nueva Ecija	5.0	6.9	1.9	.7	1.0	0.2
40	Camarines Sur	4.3	5.8	1.5	1.1	1.1	0.2
32	Iloilo	4.1	5.3	1.2	.3	1.1	0.2
189	All sites	4.5	6.3	1.8	0.8	0.9	0.2

[a]Data provided by IRRI Agronomy Department.

experiments. The low level was fixed at the subject farmer's current practice and the high level, at the maximum yield level. (The methodology of constraints research is discussed in De Datta et al 1978; results are reported in IRRI annual reports, 1974–79.) The measured yield contribution of insect control in this experiment therefore identifies the yield being lost to insects in spite of farmers' practices (Table 4). This measure of yield loss is hypothesized to be smaller than losses shown in Tables 2 and 3 because farmers may apply some low level of protection above zero.

The constraints data in Table 4 are useful for indicating how much yield is lost despite farmers' present practices. They also indicate the relative degree of yield constraints from insects, fertilizer, and weeds.

The results from 7 years of wet season trials in 4 provinces showed an average yield difference of 1.1 t/ha between farmers' present practices and high levels of fertilizer, weed control, and insect control. The high level of insect control added an average of 0.5 t/ha to yields obtained with farmers' insect control practices. In the dry season, the total gap was larger, 1.8 t/ha, and the average increase attributed to the high level of insect control was also somewhat higher, 0.8 t/ha.

Summary of yield loss information

The data suggest that yield losses from insects in the intensively cultivated experiment station fields were about 2 t/ha. Experiments in farmers' fields, where insect pressure was generally less, showed yield losses around 1 t/ha. In provinces where one crop of rice is common farmers' practice, yield losses are lower. Trials comparing insect-resistant varieties with nonresistant varieties show smaller yield losses in resistant varieties. Comparisons of farmers' present insect control practices with maximum protection practices in more than 400 constraints yield trials in 4 provinces show that despite their control practices, farmers lose 0.5 t/ha in the wet season and 0.8 t/ha in the dry season to insects.

PROFITABILITY OF INSECT CONTROL TECHNOLOGIES

The yield loss data reviewed above show that considerable rice is being lost to insects. Could this yield loss be economically saved by application of insect control measures?

To answer this question we examine some of the data from trials reviewed earlier. We have adopted certain conventions in our analysis: a constant set of prices for each insecticide, a constant price for palay across years, and a uniform cost for labor per application. (These simplifications were done to standardize prices across the different sites and years. If anything, they should bias the economic analysis toward a return to insecticide.)

The discussion uses the term economic threshold, but we have adapted it to suit the particular data sets available. Theoretically the economic threshold level (ETL) refers to that level of insect population at which control costs would roughly equal the value of the crop loss. Unfortunately the design of the experiments was such that the ETL treatments varied in interpretation. ranging from “soil incorporation of systemic insecticide” to spraying when population levels surpass critical threshold levels. For the analysis, therefore, we assume that the lowest level of insecticide application in each trial (this level was variously designated as the recommended practice, the economic threshold, or soil incorporation) can be pooled and analyzed as a single treatment which we henceforth call the economic threshold (ET). In a similar way we also assume that the next highest cost treatments can be grouped together for analysis. Thus, we evaluate the economic return from the ET, the next higher (NH), and the maximum protection (MP) levels. Treatments are also analyzed according to varietal resistance characteristics. Greater profitability of insecticide is expected on nonresistant rices because control effects on them are larger than those on resistant varieties. The average yield obtained with each treatment is used as the basis for analysis. It is assumed that the experiments showed there was a statistically significant difference in yields of the treatments being compared.

For simplicity, we assume that the decision maker is a farmer who hires all labor on a daily wage basis, owns his land (and therefore does not pay any land rent or other payment for land), and has plenty of cash with which to purchase insecticide and so pays no interest on his purchases. In a previous paper we relaxed these rather restrictive assumptions (Herdt and Jayasuriya 1981).

Method

The first step in economic analysis is to compute the cost (including labor for application) and the value of yield of each treatment. The second is to subtract, for each observation, the value of output with the control from the value of output with ET, value of output with ET from the value of output with NH, and value of output with NH from value of output with MP. The resulting figures give the added return obtained by going from one level to the next. Similar calculations are performed with successive levels of cost to compute added cost.

If added returns exceed added costs for a treatment, then using that treatment, increases a farmer's profit. However, added returns higher than added costs may not be sufficient to induce farmers to adopt a particular treatment. Small farmers operate with limited resources, particularly cash, and there are many demands competing for these resources. Therefore they invest resources only if the rate of return is sufficiently high. In many locations, including the Philippines (IRRI 1979), farmers obtain an average rate of return of around 2:l on their investments in farming inputs.

The most sensitive measure of the economic profitability of a treatment may be the marginal benefit-cost ratio (MBCR). This is computed by dividing the added return from a treatment by its added cost. A MBCR of 2.0, indicates a return of ₱2 for every ₱1 spent; if the MBCR is below 1.0, then the expenditure results in a loss.

Results

Table 5 shows the economic analysis of the experiments conducted at the four research stations during the 1972-74 dry seasons. The return on ET is most attractive on both rice types, but the difference between moderately resistant and nonresistant rices is clear. There is no incentive to go above ET with the moderately resistant rices while there is some profit involved in applying even the MP level on the nonresistant rices.

Table 6 presents the added costs, added returns, and MBCR on the additional costs for three levels of insecticides in farmers' field experiments with resistant rices in five provinces. Note that in each case the value is computed with respect to the next lower treatment: ET compared to zero application, NH compared to ET, and MP compared to NH.

Using a 2:1 rate of return, Table 6 shows that the ET treatment is the only one that would be economically attractive in all 5 sites. Average MBCRs for the MP treatment and even the NH treatment are less than 1.0 in all sites, and are negative in most cases.

The same analysis is presented in Table 7 for nonresistant varieties (available only

Table 5. Economic analysis of average performance of 3 levels of insecticide application in experiments at 4 Philippine research stations, dry seasons 1972-74.

	Moderately resistant rices [a]			Nonresistant rices [a]		
	Added cost (₱/ha)	Added return (₱/ha)	MBCR	Added cost (₱/ha)	Added return (₱/ha)	MBCR
Economic threshold (ET)	80	767	9.5	95	819	8.6
Next higher (NH)	82	–77	neg	85	365	4.2
Maximum protection (MP)	1446	1337	0.9	1386	1895	1.4

[a] Shows added cost and added return compared to the lower treatment: ET compared to control, NH compared to ET, and MP compared to NH. MBCR = marginal benefit-cost ratio.

Table 6. Added costs, added returns, and marginal benefit-cost ratio (MBCR) of 3 insecticide application levels in experiments on resistant rices in farmers' fields, Philippines, 1976-81.

Location, treatment[a]	Wet season[b]			Dry season[b]		
	Added cost (₱/ha)	Added return (₱/ha)	MBCR	Added cost (₱/ha)	Added return (₱/ha)	MBCR
Laguna						
ET	311	759	2.4	217	868	4.00
NH	254	–341	neg	338	– 512	neg
MP	1000	791	0.8	740	884	1.2
Nueva Ecija						
ET	333	1442	4.3	201	– 1178	neg
NH	1086	–140	neg	964	– 527	neg
MP	942	775	0.8	589	1240	neg[c]
Cagayan						
ET	0	– 47	n.d.[d]	0	558	n.d.
NH	1504	744	0.5	1202	– 279	neg
MP	320	124	0.4	861	698	0.8
Iloilo						
ET	140	573	4.1	254	780	3.1
NH	411	432	neg	355	– 25	neg
MP	880	68	0.1	519	1236	2.4
Pangasinan						
ET	215	186	0.9	242	660	2.7
NH	522	148	0.3	252	18	0.1
MP	1038	– 21	neg	705	145	0.2

[a]ET = economic threshold, NH = next higher above ET, MP = maximum protection. [b]Compares ET to zero, NH to ET, MP to NH. [c]MP gives a lower net return than the control, ET, or NH. [d]MBCR concept is not defined.

Table 7. Added costs, added returns, and marginal benefit-cost ratios (MBCR) of different insect control levels on nonresistant rices in farmers' fields, Philippines, 1976-81.

Location, treatment[a]	Wet season[b]			Dry season[b]		
	Added cost	Added value	MBCR	Added cost	Added value	MBCR
Laguna						
ET	451	2403	5.3	217	1891	8.7
NH	76	–1333	neg	338	–977	neg
MP[c]	816	1441	1.8	740	1643	2.2
Solana						
ET	0	1271	n.d.	74	264	3.6
NH	1732	– 449	neg	747	– 62	neg
MP	331	46	0.1	365	496	1.4

[a]ET = economic threshold, NH = next higher above ET, MP = maximum protection. [b]Compares ET to zero, NH to ET, MP to NH. [c]MP gives a lower net return than the control, ET, or NH.

for Laguna and Cagayan). As with resistant rices, the ET treatment was uniformly best. But in Laguna it was clear that all insecticide treatments gave a higher return on nonresistant rices than on resistant rices.

Summary of economic analysis

The economic analysis showed that on the average only the lowest level of application — the ET treatment — was economically profitable. This means that even though the total yield loss infarmers' field trials with resistant rices was 0.8 t/ha in Iloilo and 1.3 t/ha in Nueva Ecija in the wet season, the ET treatment, which saved 0.4 t/ha in Iloilo and 0.9 t/ha in Nueva Ecija, was the most attractive economically.

Both experiment station and Laguna farmers' field trials, which make possible a comparison of insecticide use on resistant and nonresistant rices, show there is less economic incentive to apply high levels of insecticides on resistant rices than on nonresistant rices. This illustrates one of the important advantages of built-in insect resistance — the lower economic incentive to apply high rates of insecticides saves farmers money, conserves natural enemies, reduces the potential for environmental problems; and reduces the likelihood of developing insects that are resistant to pesticides.

VARIABILITY AND RISK FROM YIELD LOSSES

The level of insect pressure varies from year to year, even for the same crop season and the same variety. Because of this inherent variability there is a certain degree of risk involved in choosing an appropriate insect control strategy. If a farmer chooses not to apply insecticide, he may suffer yield and, hence, economic losses from insect damage. If he chooses to apply a high level of prophylactic protection, he may spend more than the value of rice saved and suffer economic loss. If he follows a lower level of prophylactic protection he may sustain losses in years of infestation.

Farmers may use insecticides as a hedge against risk, i.e. they may feel that by using insecticides they can avoid large losses if insect infestation occurs. How can one evaluate whether Philippine farmers' actions are economically rational on the basis of available data?

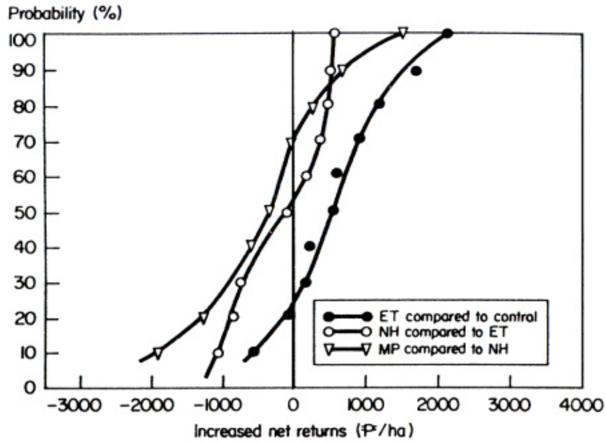
The data based on averages indicate a relatively large yield loss in the experiments reported in Table 1. Economic evaluation of the set of experiments showed that ET was the most attractive economically, especially on the moderately resistant rices (Table 5). Would the use of NH or MP reduce the farmer's risk (assuming the data represent what might happen to farmers)?

Table 8 shows a risk analysis of the available information from the experiment station trials. (See appendix.) The data were grouped by deciles so as to be interpreted as probabilities. For example, the third line means there is a 30% chance that a farmer adopting the ET will add ₱152/ha or less to his net return, or alternatively, there is a 70% chance that the treatment will add more than ₱152/ha. There is a 30% chance that applying NH will result in a loss of ₱779/ha or more. The last two columns of the line show that a farmer adopting MP stands a 30% chance of losing ₱756/ha or more. Subsequent lines are interpreted similarly.

Table 8. Risk analysis of yields obtained with 4 insecticide treatments on moderately resistant rices at 4 Philippine experiment stations, 1972-74 dry seasons.

Decile[a]	ET compared to control		NH compared to ET		MP compared to NH	
	Increased output value	Increased net return[b] (profit)	Increased output value	Increased net return[c] (profit)	Increased output value	Increased net return[d] (profit)
1	–465	–545	–1162	–1080	–310	–1918
2	0	–80	– 775	– 857	310	–1298
3	232	152	– 697	– 779	852	– 756
4	310	230	– 465	– 547	1007	– 601
5	620	540	0	– 82	1240	– 368
6	697	617	232	150	1472	– 136
7	1007	927	388	383	1550	– 58
8	1318	1237	465	470	1860	252
9	1782	1703	574	492	2248	640
10	2170	2090	667	565	3147	1539
Expected	value 767	687	– 77	– 159	1337	– 108

[a]The first line shows the lowest 10% of yield increases for the comparisons indicated, the second line shows the second 10% of yield increases for the comparisons shown, etc. [b]Cost of ET was ₱80/ha, rice valued at ₱1.55/kg. [c]Cost of NH was ₱162/ha, ₱82/ha above ET. [d]Cost of MP was ₱1,608, ₱1,446/ha above NH.



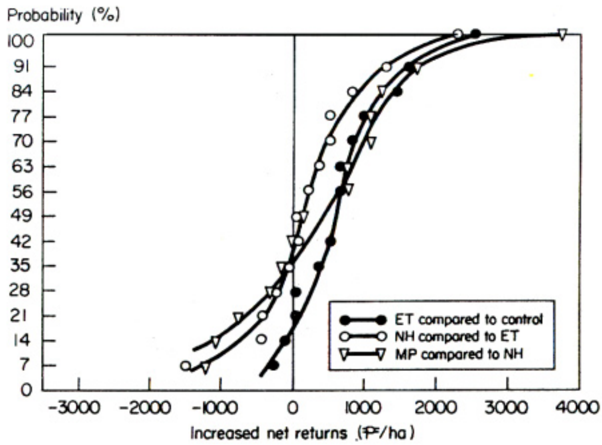
2. Probabilities of stated Increase in net returns from alternative insecticide treatments in experiments on moderately resistant rices at 4 research stations, Philippines, 1972-74 dry seasons.

This analysis clarifies the difference between risk of yield loss and risk of economic loss. Using the ET entails a 10% chance of having a lower yield than the control and a 20% chance of having a lower net return than the control (or alternatively, a 90% chance of having a higher yield and an 80% chance of having a higher net return than the control). Using the NH entails a 40% chance of having a lower yield than with ET and a 50% chance of having a lower net return. Thus the NH would seem to be a questionable practice. The MP treatment entails a 10% chance of having a lower yield than the NH, but a 70% chance of having a lower net return. Clearly, the MP treatment entails a much larger economic risk than the ET. The last line of the table shows the expected value of the increased output value (the mean) which is the same as the added return shown in Table 5. Thus, whether based on the average or on risk, ET is the most attractive treatment.

The same information is shown graphically in Figure 2. The line comparing ET to control shows a 75% chance of a positive increased net return, while the NH compared to ET has a 50% chance of an increased net return and the MP compared to NH has a 70% chance of a decreased net return. Figure 3 shows the same kind of risk analysis for nonresistant rices. In this case the conclusions are not as clear cut. The ET has a lower probability of a negative change in profit, but the MP has a higher probability of getting an increased net return exceeding ₱750/ha. This reflects the greater likelihood of insect damage on nonresistant varieties. Figure 4 shows the same type of analysis for the Iloilo data. The ET compared to control shows a larger increase in net return at every level of probability than either of the two other treatments. Thus, it is less risky for all levels of increased net return.

RECOMMENDED INSECT CONTROL RESEARCH

The data reviewed give some indication of the extent of yield loss from rice insects in the Philippines and the economic gains that might be obtained from preventing a portion of the yield loss. They also illustrate that it is not economically possible to prevent 100% of the yield loss — and that will always be the case. Thirdly, they



3. Probabilities of stated increase in net returns from alternative insecticide treatments in experiments on nonresistant rices at 4 research stations, Philippines, 1972-74 dry seasons.

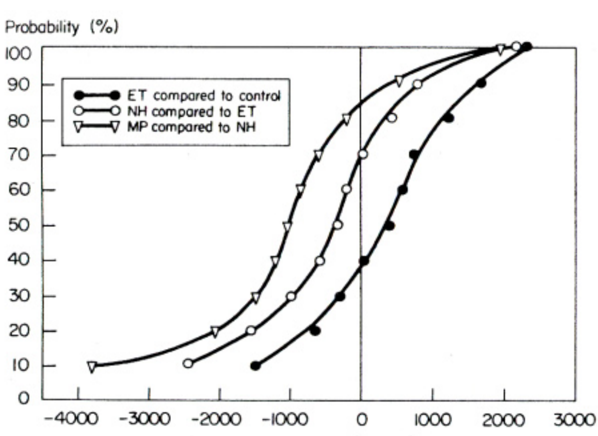
illustrate that for the cases considered, no reduction in economic risk is achieved by applying high levels of insecticide.

The value of these results for making recommendations to farmers is somewhat limited, however, because the experiments were not designed for this purpose. In some cases we have pooled across sites or across treatments data that should not be pooled. In other experiments no potentially recommendable treatments have been included. In some cases available observations are not enough to permit a risk analysis or even a judgment about variability within a location.

We recognize that research may be carried out for purposes other than making recommendations, but believe that *some* experiments should be designed and used to make recommendations. The following guidelines would result in data that can be analyzed for recommendations to farmers.

Potentially recommendable treatments

Farmers compare the value of yield loss prevented with expenditure made.



4. Probabilities of stated increase in net returns from alternative insecticide treatments in experiments in farmers' fields, Iloilo, Philippines, 1976-79 wet and dry seasons.

Experience has shown that, because of their high cost, maximum or complete protection treatments are seldom, if ever, economically attractive. Low-cost treatments may be attractive if insects occur with enough frequency and if the treatments are effective in controlling the insects. A potentially recommendable treatment is defined as one which has a cost that is reasonable, considering farmers' resources, and which is likely to yield a return in excess of its cost. We suggest the following treatments be included in experiments designed for making recommendations:

1. A zero insecticide treatment.
2. A treatment approximately equal in value to 200 kg of palay.
3. A treatment approximately equal in value to 400 kg of palay.
4. A treatment approximately equal in value to 600 kg of palay.

These monetary values should be determined at the beginning of the period and the treatments held constant. In 1983 in the Philippines, these guidelines suggest treatments costing about ₱300, ₱600, and ₱900 per hectare. To yield a MBCR exceeding 2.0 they must prevent 400 kg, 800 kg, and 1,200 kg of yield loss, respectively, consistently and averaged over a large number of cases.

The chemicals used and guidelines for timings of thresholds will, of course, have to be determined with those upper limits on expenditure in mind. The entomologists must use their best judgment for the technical specifications — within the limit of cash specified, the best material, best timing, and best practice should be used. Above all it is important to "cost out" the maximum level of chemicals and labor that are permitted for each treatment prior to finalizing the design. Prices received by farmers should be used, *not* "official" prices.

A MP treatment might be included simply to indicate the total yield loss being sustained. Likewise, treatments to identify what kinds of insects are causing the yield loss or at what crop stage the loss is occurring may be useful. However, such treatments cannot be used to generate recommendations, because they entail MP at all stages, or all stages except one, and such high levels of protection will never be profitable.

Testing of treatments

Once a set of treatments has been designed, they should be tested at a series of locations over a number of years to ensure that enough information is obtained to give the researcher an idea of the variability of insect attack and damage in a given ecosystem. This usually means that trials must be conducted in farmers' fields. The use of fields as replications within an area for which a single recommendation is to be made is a technique for increasing the representativeness of experimental results (Zandstra et al 1981). It does, of course, mean that results on individual fields cannot be analyzed individually but must be pooled. Thus, one might:

1. Conduct trials at seven different farmers' fields each season.
2. Keep treatments constant for a 3-year period.

The other inputs (fertilizer, cultural practices, varieties, etc.) should be kept at levels similar to those being used by farmers in the research area. In particular, it is unwise to use very high levels of fertilizer or old nonresistant varieties if farmers are not doing so. Either system will overestimate the damage farmers are likely to suffer.

(The objective of the trials being described is not to test whether a particular chemical kills a particular insect, but rather to develop a treatment to recommend to farmers.)

Treatments must be held constant over the entire period or else the analysis made by pooling the results will suffer from some of the same inadequacies as in our illustrative analysis. Methods of determining ET, if used in the experiments, should also be held constant to permit ET evaluation under varying conditions.

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DISCUSSION

NAGATA: How did you decide the economic threshold in your experiment? Was it based on the populations of several pest species or some key pests?

HERDT: The entomologists who conducted the experiments determined the economic thresholds. Because the experiments were conducted over a period of years, I suspect that the thresholds and method for their determination changed over time.

KENMORE (comment): In the Philippines, farmers often do not use insecticides according to recommendations. Underdosing is very common in IRRI's cropping system studies and in BPI's crop protection network. It has also been shown that underdosing achieves control and farmers arrive at a technology more economical than standard recommendations. Farmer's perception and behavior should be incorporated in the design of research trials to develop the most appropriate recommendations.

Appendix Table 1. Yields (t/ha) of moderately resistant rices at 4 insecticide application levels, at 4 Philippine experiment stations, 1972-74 dry seasons.

Control		ET			NH			MP		
Yield	Rank	Yield	(3-1)	Rank	Yield	(6-3)	Rank	Yield	(9-6)	Rank
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
4.4	13	5.5	1.1	17	5.1	–0.4	6	5.6	0.5	5
4.6	16	5.2	0.6	13	4.7	–0.5	5	5.0	0.3	4
3.8	5	4.6	0.8	15	4.5	–0.1	9	5.1	0.6	6
4.8	17	4.4	–0.4	1	4.9	0.5	21	5.8	0.9	11
4.4	12	5.3	0.9	16	5.6	0.3	16	5.2	–0.4	1
3.0	2	3.4	0.4	10	3.1	–0.3	7	3.2	0.1	3
5.1	19	5.1	0	3	5.5	0.4	18	6.5	1.0	14
4.2	11	4.4	0.2	7	3.9	–0.5	4	4.9	1.0	12
4.0	8	4.7	0.7	14	4.8	0.1	11	5.8	1.0	13
3.9	6	5.2	1.3	20	4.7	–0.5	3	4.7	0	2
2.9	1	3.4	0.5	12	3.7	0.3	14	5.9	2.2	21
4.9	18	5.1	0.2	8	5.2	0.1	10	6.5	1.3	16
3.5	4	4.7	1.2	18	4.4	0.3	17	5.0	0.6	7
4.6	15	4.7	0.1	5	4.9	0.2	12	5.7	0.8	9
5.6	20	6.0	0.4	11	5.7	–0.3	8	6.8	1.1	15
3.9	7	5.6	1.7	21	4.8	–0.8	1	6.3	1.5	18
4.2	10	4.4	0.2	6	4.8	0.4	20	6.8	2.0	20
5.7	21	5.5	–0.2	2	5.8	0.3	15	6.5	0.7	8
4.1	9	5.3	1.2	19	4.6	–0.7	2	6.5	1.9	19
3.1	3	3.5	0.4	9	3.9	0.4	18	5.3	1.4	17
4.4	14	4.4	0	4	4.6	0.2	13	5.4	0.8	10

Appendix Table 2. Yield data from Appendix Table 1 arrayed and grouped by deciles.

Decile[a]	Yield of control (t/ha)	Increased yield of ET over control	Increased yield of NH over ET	Increased yield of MP over NH
(1)	(2)	(3)	(4)	(5)
1	2.95	–0.30	–0.75	–0.20
2	3.30	0.00	–0.50	0.20
3	3.85	0.15	–0.45	0.55
4	3.95	0.20	–0.30	0.65
5	4.15	0.40	0.00	0.80
6	4.30	0.45	0.15	0.95
7	4.40	0.65	0.25	1.00
8	4.60	0.85	0.30	1.20
9	4.85	1.15	0.37	1.45
10	5.47	1.40	0.43	2.03

[a] Original data consist of 21 points, the 2 lowest are averaged to obtain decile 1, the next 2 to obtain decile 2, etc. Decile 10 is formed from the 3 highest observations.

Appendix Table 3. Computed[a] cost of insect control treatments in farmers' fields and research stations, Philippines, 1972-81.

Location	Cost (₱/ha)					
	Wet season			Dry season		
	ET	NH	MP	ET	NH	MP
			Resistant rices			
4 research stations	n.a.	n.a.	n.a.	80	162	1608
Pangasinan	215	737	1775	242	494	1199
Iloilo	140	551	1431	254	609	1128
Nueva Ecija	333	1419	2361	201	1165	1754
Laguna	311	565	1568	217	555	1296
Cagayan	0	1504	2393	0	1202	2063
			Nonresistant rices			
4 research stations	n.a.	n.a.	n.a.	95	180	1566
Laguna	451	527	1343	217	555	1295
Cagayan	0	1732	2594	74	821	1186

[a] All materials were priced at the 1981 insecticide prices shown in Appendix Table 4; palay was valued at ₱1.55/kg.

Appendix Table 4. Prices of chemicals used in economic profitability analysis of insect control treatments.

Common name	Brand name	Unit	Price (₱)
Monocrotophos	Azodrin 16.8 EC	liter	48.79
Monocrotophos	Azodrin 202 R 30	liter	81.33
Monocrotophos	Nuvacron 200 SCW 30	quart	69.85
Diazinon	Basudin 10 G	kg	9.81
Carbaryl	Sevin 85 WP	kg	66.00
Carbofuran	Furadan 3 G	16.7-kg bag	155.35
BPMC	Hopcin 50 EC	liter	63.05
BPMC + chlorpyrifos	Brodan 31.5 EC	liter	87.89
Endosulfan	Thiodan 35 EC	liter	63.10
Gamma – BHC	Agrocide 26 WP	kg	39.75

PROJECTED TREND IN THE USE OF INSECTICIDES IN RICE INSECT PEST CONTROL

H. Ishikura

Cramer (1967) estimated world rice loss caused by insect pests at 121 million t, which was 27.5% of potential production (Table 1). The loss was extremely high in Asia (except China) reaching 32.1%. Recent statistics compiled by the Food and Agriculture Organization of the United Nations indicated that the loss of rice caused by insect pests is highest among three major cereals of maize, rice, and wheat. Considerable yield increases obtained as the result of chemical control justify the use of insecticides in tropical countries. At the International Rice Research Institute (IRRI), untreated plots yielded 3.1 t/ha and plots treated with insecticides yielded 5.8 t/ha (a yield increase of 87%) from 1964–1971 (Pathak and Dyck 1974). Similar experiments on farmers' fields in the Philippines showed a 20-25% yield increase.

In 6 districts of Taiwan, the increase in yield of treated crops over that of untreated crops ranged from 8.9 to 23.4% in the first crop (av 15.4%) and 13.8 to 54.2% in the second crop (av 29.9%) (Table 2).

Even in Japan, where damage caused by rice insect pests is not as serious as in tropical Asian countries, loss of brown rice per hectare decreased from an average of 419 kg/ha in 1949-51, when rice insect pest control with insecticides was just beginning, to an average of 153 kg/ha in 1979-81, when insecticide use had become extensive. Taking the average yield of brown rice as 5 t/ha, that decrease in the loss of yield amounted to 5.3%.

Rice insect pest control with insecticides has a remarkable potential to increase rice yields. We expect greater use of insecticides, because other control measures such as the utilization of rice plant resistance to insect attack, or the intensification of the role of biotic control agents such as predators and parasites are slow to develop and are limited.

The introduction of high production technology involving rice varieties with high tillering ability, denser plant spacing, and associated high fertilizer applications seems to have increased the occurrence of rice insect pests. Figure 1 shows increased occurrence of rice insect pests with increased rate of fertilizer application and higher plant densities from 1956 to 1980 in Japan. Intensity of infestation gradually increased from 1956 to 1970. That period coincided with the introduction and dissemination of high production technology. Although data on the application of nitrogen fertilizers are not available after 1965, it is estimated from the total supply of nitrogen fertilizer to Japanese agriculture that the input into rice cultivation

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Table 1. Loss of rice caused by insect pests (Cramer 1967).

Region	Potential production (thousand t)	Loss caused by insects (thousand t)	Loss (%)
North and Central America	5,369	183	3.4
South America	9,396	3 29	3.5
Europe	1,865	37	2.6
Asia (except China)	325,950	105,700	32.1
China	86,848	13,027	15.0
Africa	8,451	1,217	14.4
Oceania	40	1	2.5
USSR	877	234	26.7
Total	438,796	120,728	27.5

continued to increase until the mid-1970s. Higher plant densities were achieved by the introduction of transplanting machines in the late 1960s. The number of panicles per square meter continued to increase into the late 1970s. Insect infestation decreased, however, probably because of lower rice stem borer infestations, the widespread planting of high tillering varieties that are less damaged by the stem borer, and the mechanization of harvesting, which destroys the overwintering larval population.

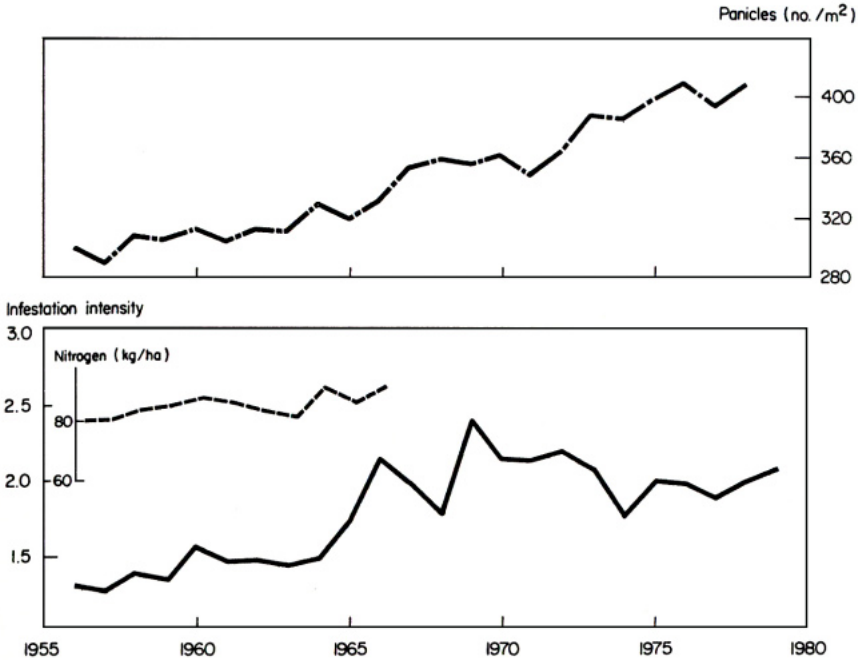
The technology developed at IRRI in the early 1960s encountered similar difficulties of increased occurrence of insect pests and diseases. If the crop is not protected from them, high production cannot be attained. Therefore, production increases attempted through yield increases will result in correspondingly higher infestations of rice insect pests. That in turn will require increased use of insecticides. This paper deals with:

- the trend of rice insect pest control with insecticides in Japan; Taiwan, China; Indonesia; the Philippines; and Thailand;
- factors involved in the use of insecticides:
- projected use of insecticides on rice insect pests in Asia.

Table 2. Paddy rice yields and losses caused by insect pests in Taiwan, 1973-75 (Ku et al 1980).

District[a]	Yield (t/ha)				Av yield loss (%)	
	1st crop		2d crop			
	Chemical protection	Natural infestation	Chemical protection	Natural infestation	1st crop	2d crop
Taipei	5.1	4.5	4.3	3.1	10.6	14.3
Hsinchu	4.8	3.9	4.0	3.4	19.1	13.8
Taichung	5.6	4.6	5.5	4.3	18.5	21.6
Chiayi	6.2	5.5	5.1	3.8	11.6	26.5
Tainan	6.0	5.5	4.5	2.1	8.9	54.2
Kaohsiung	6.4	4.9	5.2	2.8	23.4	45.9
Av	5.7	4.8	4.8	3.3	15.4	29.9

[a]Two experimental sites (each 0.3 ha) were set up in each district.



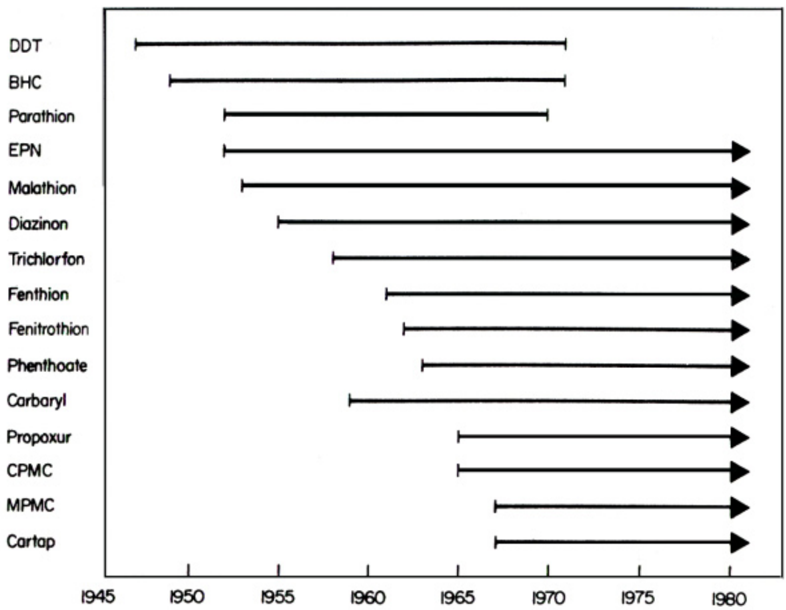
1. Plant density, fertilization, infestation intensity (total infested areas/planted area), and nitrogen fertilizer application in Japan.

INSECTICIDES USED FOR RICE INSECT PEST CONTROL

Japan and Taiwan, China, have used insecticides to control rice insect pests since modern insecticides were introduced after World War II.

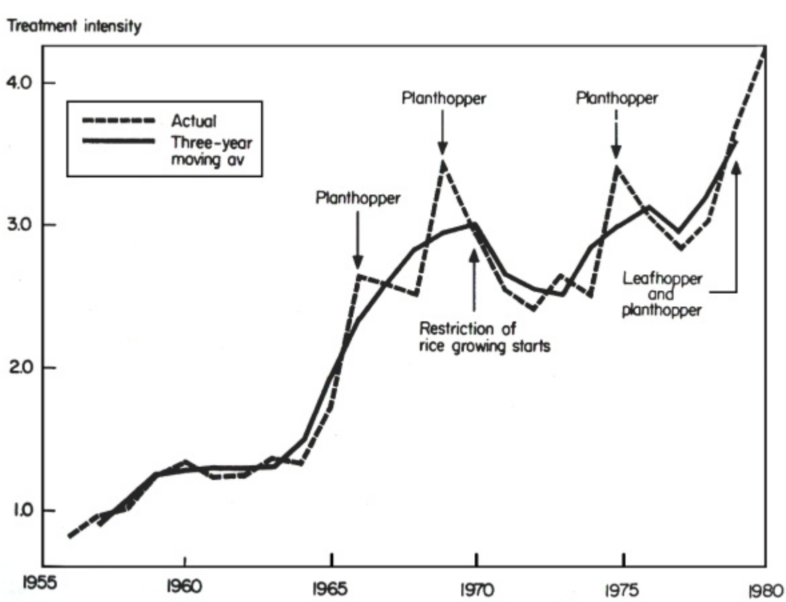
The introduction of DDT and BHC in the late 1940s and of parathion in the 1950s established the technical basis for pest control with insecticides in Japan. The insecticides were effective against stem borers, leafhoppers, and planthoppers. To increase rice production in the 1950s. the Japanese Government subsidized insecticides and application equipment, and provided technical support to farmers. That caused the use of insecticides for rice insect pest control to spread like wildfire.

Figure 2 shows the sequence of introduction of major insecticides for rice insect pest control since the late 1940s. Figure 3 shows the ratio of the treated area for control of 12 major species of rice insect pests to the total planted area from 1956 to 1980. Although the ratio peaked in 1966, 1969, and 1975 due to outbreaks of leafhoppers and planthoppers, the 3-year moving average shows a kind of sigmoidal growth curve during 1956-70. The drop for about 1970-73 was caused probably by the farmers' diminished motivation to protect the rice crop, because the government had restricted rice growing to reduce surplus production. After 1973, however, the ratio again increased until 1980. That increase was partly due to the increase in the use of multitarget, mixed formulations of insecticides. The area treated was repeatedly infested with insect pests that could be controlled by multitarget mixed formulations.



2. Succession of major insecticides used for rice insect pest control in Japan.

Taiwan, China, also has a long history of insecticide use for rice insect pest control. The Taiwan Provincial Food Bureau began free distribution of insecticides, fungicides, and equipment to farmers in 1953. The program continued until the late



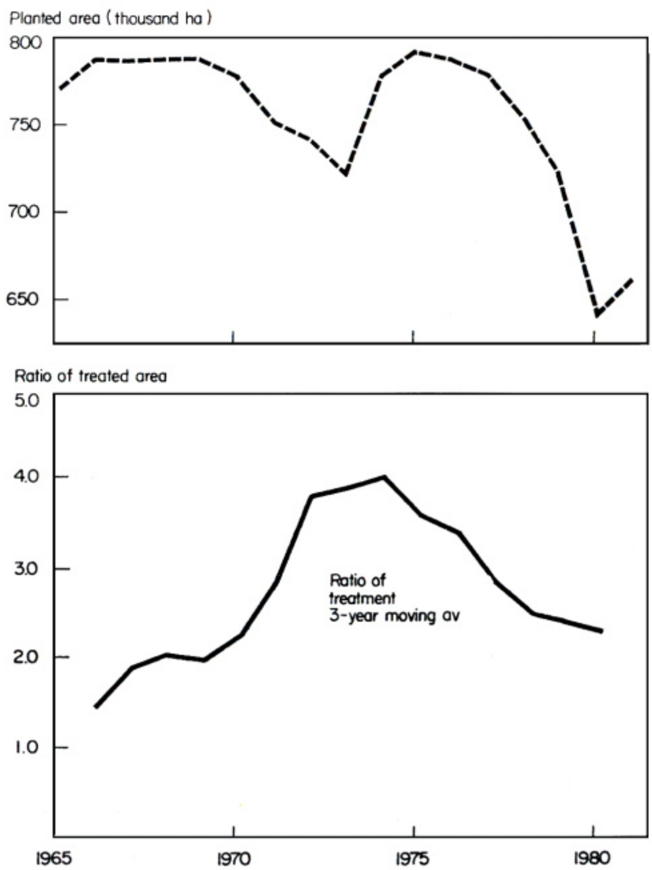
3. Trend of the ratio of treated area to planted area of rice in Japan.

1960s. That program encouraged the use of insecticides for rice insect pest control by farmers throughout the island.

Figure 4 shows the ratio of treated area to planted area in Taiwan 1965-80. In this case, too, the 3-year moving average showed a sigmoidal growth curve as in Japan from 1966 to 1975.

In Taiwan, however, the ratio started to decrease after 1975 and did not show the second step increase observed in Japan. While the area planted to rice decreased in the early 1970s, the ratio of treated area to planted area continued to increase considerably. In the later half of the 1970s, however, the ratio decreased parallel to the decrease in planted area. The policy to discourage rice cultivation in Taiwan seems to have made rice farmers reluctant to control rice insect pests during that period.

Intensification of pest control with insecticides will contribute to increased rice yields, but high production rice technology will increase the occurrence of rice insect pests. For those reasons, the existence of some relation between rice yield and



4. Trend of the ratio of treated area to planted area of rice in Taiwan.

intensity of pest control with insecticides is expected. Figure 5 shows the relation of rice yield and the intensity of rice insect pest control with insecticides in Japan. The relationship expressed itself as an exponential curve. When the rice crop was treated more intensively with insecticides, higher yields were expected.

No comparable data from other countries are available to the author, except some fragmentary ones in Thailand, Indonesia, and the Philippines.

In Thailand, the rice area treated with insecticides in the early 1960s fluctuated between 125,000 and 268,000 ha, corresponding to 1.9 to 4.5% of the total planted area, a much lower percentage of treated area than in Japan and Taiwan during the same period.

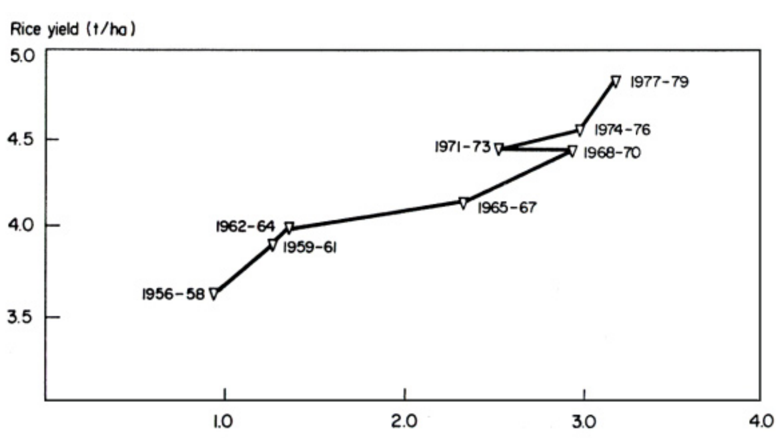
In Indonesia, the total treated area in the 1970 dry season and the 1970-71 wet season crops reached 1.3 million ha, about 16% of the total planted area (Muljani 1972). Arif (1980) reported that the total area of rice fields attacked by insect pests was 351,000 ha in 1974 and 1 million ha in 1978.

In the Philippines, 188,000 ha of rice fields or about 6% of the total area planted to rice was treated for stem borers, armyworms, stink bugs, and caseworm in 1964-65 season under the 303 project (Ishikura 1975). Tadefa (1981) reported that 54% of insecticides sold in the Philippines was used in rice insect pest control. Of 3.6 million ha planted to rice, 35% of the area was treated with granular insecticides and 25% with liquid insecticides.

FACTORS INVOLVED IN THE USE OF INSECTICIDES FOR RICE INSECT PEST CONTROL

Technical factors

Rice insect pest control with insecticides has become feasible with the development of insecticides effective in the proper formulations and efficient application equipment. The rapid control of the rice stem borer and leafhoppers and planthoppers in Japan in the early 1950s was realized by the introduction of DDT,



5. Relation between control intensity and rice yield in Japan (data shown by the 3-year average).

BHC, and parathion in dust formulation that could be applied to the crop. The development and commercialization of a series of insecticides, including wide-spectrum insecticides, has resulted in low populations of hard-to-control rice insect pests.

Heinrichs et al (1979) defined a rice pest management system in tropical Asia in terms of insect pest resistance, effective insecticides, and biological control in the context of augmentation of natural enemies. The chemical control component is available for nine major rice pests: whorl maggot, green leafhopper, zigzag leafhopper, whitebacked planthopper, brown planthopper, yellow stem borer, striped stem borer, leaffolder, and rice bug. The varietal resistance component is available only for the green leafhopper and the brown planthopper. No biological component in the context of augmenting natural enemies of the pests is available.

Improved rice insect pest control with insecticides could be expected by further development of more effective and economical insecticides and their judicious use. Rice fields, in particular submerged fields, can be easily polluted by insecticides. Therefore, insecticides used in rice insect pest control should be safe to humans, animals, and fish.

The rice yield gains that can be realized by insecticide treatment depend on the yield potential of the crop, extent of insect damage, and the effectiveness of insecticide control. Because loss is positively related to the population density of insect pests, and population densities of rice insect pests fluctuate by season, by year, and by site, the timely application of insecticides is important. Therefore, monitoring systems are necessary. The rapid development of insecticide use for rice insect pest control in Japan and Taiwan, China, was largely due to pest detection and forecasting programs. Such programs should be established in countries where they are lacking, and be augmented in countries where they are weak.

A rational approach to chemical control of rice insect pests requires the determination of an economic threshold (ET). ET data for the major insect pests of rice have been reported for India (Singh 1980), Japan (Kiritani 1981), and the Philippines (Litsinger et al 1980). In establishing ET, yield loss in relation to the population density of insect pests, potential yield of rice, and cost of control are considered. ET will be set high if the potential yield is low, the loss caused by injury is small, and the control cost is high.

Socioeconomic factors

Pesticide control of rice insect pests is an economic issue. Unless the control profits farmers, they will not practice it. Pest control becomes a social need in countries where the food supply is short and the governments adopt policies to increase rice production.

In Japan and Taiwan, where increased rice production had a high priority, the governments subsidized rice insect pest control with insecticides. Those policies had a favorable impact on the production and supply of insecticides. Before the oil crisis of 1973 and soaring energy costs, the price of insecticides consumed for rice insect pest control in Japan went down as demand went up. Table 3 shows the cost of the insecticides used for controlling the striped stem borer.

Using the cost of insecticides shown in Table 3, and converting that to the

Table 3. Insecticide cost for control of first and second generations of the striped stem borer in Japan, 1956-79.[a]

Year	Insecticide cost (US$/ha)						
	DDT EC	BHC (dust)	Parathion EC	Parathion (dust)	Fenitrothion EC	Fenthion EC	Diazinon G
1956	13.66	14.61	21.31	24.06			
60	11.00	11.39	16.47	20.58			
65	9.64	10.42	13.33	18.31	16.58	16.38	
70					14.25	13.83	23.75
75					21.47	20.06	41.70
79					31.25	30.21	65.33

[a] EC = emulsifiable concentrate, G = granular.

equivalent price of rice at the government purchase price each year, we find that the equivalent amount of rice it took to pay for the insecticides went down although the cost for insecticides went up from 1956 to 1979 (Table 4). The reason is that government support price increases outstripped insecticide price increases during the period.

As indicated in Figure 3, the ratio of treated to planted areas increased from – 1 in 1956 to 4.2 in 1981. Assuming that insecticides have been applied 4 times a season in recent years, the estimated amount of rice to cover the total cost of insecticide application will be 50-118 kg rice/ha, double the amount of rice required in 1979 for striped stem borer control. The yield loss caused by insect pests decreased from 420 kg to 150 kg rice/ha. That is an effective yield increase of 270 kg rice/ha. The profitability of rice insect pest control with insecticides in Japan is clear.

In the Philippines, Litsinger et al (1980) reported that a single application of carbofuran to protect the vegetative stage of the crop cost US$30.00/ha, and increased the yield of single-crop transplanted rice by 1.3 t/ha, valued at $196.00. In second-crop transplanted rice, the yield increase was 0.5 t/ha, valued at $75.00.

PROJECTED USE OF INSECTICIDES ON RICE IN THE FAR EAST

The International Rice Commission projects that of the 102% production increase anticipated in all developing regions from 1974-76 to the year 2000, 74% will be from

Table 4. Government purchase price of rice and the amount of rice required to cover the cost of insecticides for striped stem borer control.

Year	Price of rice (US$/kg)	Amount of rice (kg/ha) to cover insecticide cost
1956	0.18	76-135
60	0.19	59-111
65	0.29	33- 62
70	0.38	29- 62
75	0.84	20- 49
79	1.19	25- 54

Table 5. Harvested area, yield, and production of rice in developing regions in 1974-76 and projection for the year 2000.[a]

Region	Harvesting area (million ha)		Yield (t/ha)		Production (million t)		Rate of increase	Yield contribution
	1974-76	2000	1974-76	2000	1974-76	2000	(%)	(%)
Africa	3.8	8.6	1.4	2.2	5.4	18.8	248	37
Far East	66.7	98.5	2.0	3.4	169.2	330.5	95	80
Latin America	7.4	13.5	1.9	2.2	13.9	29.4	112	20
Near East	1.2	2.0	3.8	5.1	4.5	10.2	127	36
Developing regions	79.1	122.6	1.9	3.2	193.0	388.9	102	74

[a] International Rice Commission (1982).

yield contribution (Table 5). The yield contribution to production increase in the Far East is anticipated at 80%, with average yields going from 2 t/ha to 3.4 t/ha. That will likely mean an increased demand for insecticides for rice insect pest control.

The average yields estimated for the Far East in 2000 correspond to Taiwan yields in the mid-1960s. If we assume that the Far East in 2000 will have about the same ratio of treated area to planted area as Taiwan had in the mid-1960s (Fig. 4), we can estimate insecticide usage in the Far East in 2000. Using the Taiwan ratio and applying it to an estimated harvest area of 98.5 million ha, and assuming a dosage of 0.5 kg active ingredient (ai)/ha, we can predict that the Far East will be using 74,000 t ai/ha in the year 2000.

The yield contribution to production increases in Africa, Latin America, and the Near East is expected to be considerably lower than that in the Far East. Therefore, there is a lower probability that insecticides for rice insect pest control will reach high levels in those regions.

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DISCUSSION

KENMORE: 1) We need to separate the effect of increased fertilizer use from that of increased insecticide treatment intensity. Because fertilizer use is highly correlated with insecticide use, yield increases that appear to be due to insecticide treatment intensity might be due to fertilizer use. 2) Because the area planted to rice in Japan has been reduced, insecticide treatment intensity may increase because farmers spend the same amount of money, although less land is planted to rice.

ISHIKURA: 1) Yes, there will be a close positive correlation between the consumption of fertilizer and that of pesticides. Application of nitrogenous fertilizer at high dosage induces a high incidence of insect pests and diseases. This was experienced in Japan where fertilizer supplies decreased during World War II and restored after the war. The area infested by the rice stem borer, and the light trap records of the same pest and of the green leafhopper, reflected the fertilizer decrease and increase. 2) Yes, that is true, mainly because distributors of insecticides, including agricultural cooperatives, endeavor to sustain their sales inspite of the actual decrease in the area planted to rice.

PRESENT AND FUTURE DIRECTIONS OF CHEMICAL CONTROL RESEARCH

TRENDS IN THE USE OF CHEMICAL INSECTICIDES

R. L. Metcalf

Insect pest resistance to insecticides is a critical problem that reduces man's ability to control important pests of both agriculture and public health. Insecticide resistance is also linked with such major problems as pest resurgence, the development of secondary pests, adverse effects of pesticides on human health and environmental quality, and the escalating costs of crop production. At the most recent tally in 1980, insecticide resistance was documented in 428 species of insects: 260 pests of agriculture and 168 pests of human and animal health. Multiple resistance of pest species. or insect resistance to several of the various chemical classes of insecticides, is a far more serious phenomenon. As of 1980, 2-stage resistance was documented in 105 species, 3-stage resistance in 64 species, and 4-stage resistance in 26 species. At least 14 major insect pests are now resistant to all 5 classes of insecticides (DDT, lindane / cyclodienes, organophosphates, carbamates, and pyrethroids).

Because of the greatly increased costs of discovery and development of new types of insecticides, it is important to slow the development of resistance so as to preserve the usefulness of present-day insecticides. I discuss in this paper the principles of insecticide management that will minimize the development of resistance as well as decrease the incidence of the associated phenomena of pest resurgence and secondary pest development.

The introduction of DDT for insect pest control almost 40 years ago began a period of steadily increasing use of chemical insecticides, both quantitatively and qualitatively, that has continued almost unabatedly to the present. Over this period the production of insecticides in the United States has increased from about 45 million kg in 1940 to about 274 million kg in 1980. At the same time the number of individual chemical compounds sold as insecticides has increased from about 10 in 1940 to about 300 in 1980. Enormous quantities of especially cheap and relatively effective insecticides have been applied to agricultural lands throughout the world. The cumulative production and use of DDT is estimated as >2.7 billion kg; that of toxaphene is >1 billion kg. Entomologists have sought to exploit the use of

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insecticides to the uttermost by attempting to exterminate such insect pests as the gypsy moth *Lymantria dispar,* the Japanese beetle *Popillia japonica,* the fire ant *Solenopsis invicta,* the yellow-fever mosquito *Aedes aegypti,* and even the disease malaria through insecticidal attack on its *Anopheles* spp. mosquito vectors.

The use of insecticides has given man new insights into the possibilities of maximizing agricultural production through crop protection and of vastly improving human health and longevity by controlling vector-borne diseases. At the same time, however, the almost total reliance on insecticides for insect pest control throughout most of the world has produced some disturbing ecological and economic imbalances with grave consequences to crop production, human health, and environmental quality. Pickett's (1949) statement that "while we can now control almost any specific pest . . . nevertheless the problem of controlling pests is more acute than ever" is just as true today as it was 30 years ago. Smallman (1964) put it in more general terms, that "while insecticides may be winning the individual battles, they are not winning the war." That is a statement with which few entomologists could disagree. Today applied entomology throughout the world is in the process of appraising the techniques and philosophy of chemical insecticide use so as to remedy the technological, economic, and sociological problems caused by injudicious and overzealous use of such insecticides.

Insect resistance to insecticides is the most critical problem facing economic entomologists. Resistance in various pest species not only reduces man's ability to control those pests, but also is linked with pest resurgences, development of secondary pests, adverse effects of pesticides on human health and on environmental quality, and spiraling economic costs of crop production. Thus insect pest resistance to insecticides has become a distinct threat to continuous and profitable crop production throughout the world.

ECONOMICS OF INSECTICIDE USE

Several factors effect a rapid increase in the cost of insecticides: 1) pesticides are largely petrochemical and their prices are therefore linked to the escalating cost of this increasingly scarce material; 2) newer, effective insecticide molecules are much more sophisticated in chemical structure and require many more synthetic steps; 3) developmental costs for pesticides have increased manyfold during the past 30 years because of inflation and increasingly stringent registration requirements.

Rising costs of insecticides

The average U.S. wholesale value for well-established insecticides rose from \$1.50/kg in 1970 to \$4/ kg in 1977, a rate of 21.7%/year (doubling time 3.2 years). Increases per kilogram reported over this period included \$0.60 to \$0.84 for toxaphene, \$1.74 to \$2.27 for malathion, \$1.00 to \$2.10 for methyl parathion, and \$1.45 to \$2.20 for methoxychlor (USDA 1978a). The trend is likely to continue and has important implications for crop protection because of relatively static farm crop prices over the past decade.

Increasing complexity of insecticides

Newer insecticide molecules are more sophisticated in chemical structure and this complexity is decisive in determining ultimate price to the consumer. The older organochlorines such as DDT, BHC, and toxaphene are produced by one-step syntheses from readily available precursors and are currently priced at US$0.66-0.88/kg. Aldrin ($3.01) and parathion ($1.91) require two steps; dieldrin ($5.15). endrin ($6.60), and malathion ($2.27) require three steps. In contrast the synthetic pyrethroid allethrin ($89. 10) is produced by a 13-step synthetic process. This degree of sophistication is typical of the newest types of insecticides such as the synthetic pyrethroids and growth regulators methoprene and diflubenzuron, which currently sell at $110-880/kg. Thus a change from DDT, which once sold for $0.40/kg, to these new insecticides represents a price increase of more than 100 times. Although the newer molecules are initially about 10-fold more effective so that field applications are currently made at 0.1-0.2 kg/ha, this differential in rate of usage will decrease rapidly under the impact of insecticide resistance (Elliott et al 1978).

Costs of insecticide development

The cost of research and development leading to commercialization of a new insecticide has increased dramatically in the last 20 years. Over the same period the average developmental costs per marketable product increased from about US$ 1 million in 1956 to about $20 million in 1977 (Metcalf 1980). Well over 1 million compounds have been screened for insecticidal activity. For each new product, 1,800 compounds were screened in 1956, 3,600 in 1965, 5,040 in 1969, and 10,000 in 1972 (Johnson and Blair 1972). The newer compounds require many more synthetic steps and more costly production facilities. Governmental requirements to demonstrate the safety and efficacy of new products are becoming increasingly rigorous and in the U.S. are estimated to have added about one-third to the increased costs of new products. Such increased regulation is inevitable as the world becomes more conscious of the dangers of unregulated pesticide usage.

INSECT RESISTANCE TO INSECTICIDES

That insect pests acquire resistance or tolerance for insecticide action has been known for 69 years. It was first observed in 1914 in the San Jose scale *Aspidiotus perniciosus* selected by lime sulfur spray, and in 1916 in the California red scale *Aonidiella aurantii* and black scale *Saissetia oleae* selected by hydrogen cyanide (Metcalf 1955). By 1946, insecticide resistance was present in about 11 species. The codling moth *Laspeyresia pomonella* and the peach twig borer *Anarsia lineatella* showed resistance to lead arsenate; the citricola scale *Coccus pseudomagnoliarum,* to hydrogen cyanide; the cattle tick *Boophilus microplus* and the blue tick *B. decoloratus,* to sodium arsenite dip; the citrus thrips *Scirtothrips citri* and the gladiolus thrips *Taenothrips simplex,* to potassium antimonyl tartrate; and the wallnut husk fly *Rhagoletis completa,* to cryolite (Brown and Pal 1971). The prognostication for chemical insect control was poor. However, little scientific attention was given to insecticide resistance development, which is nothing more than accelerated micro-evolution. Insecticide resistance began to receive the attention it deserved only after the introduction of DDT, and when resistant strains of various insects appeared: the housefly *Musca domestica* in Sweden and Denmark in 1946. the mosquitoes *Culex pipiens* in Italy and *Aëdes sollicitans* in Florida in

1947, the bedbug *Cimex lectularius* in Hawaii in 1947, and the human body louse *Pediculus corporis* in Korea and Japan in 1951 (Brown and Pal 1971).

With the steady proliferation of new insecticides and their increasing use in insect control programs, the number of scientifically documented cases of insect resistance to insecticides has increased at an exponential rate, encompassing 224 species in 1970, 364 in 1975, and 428 in 1980 (Table 1). Although most early examples of insecticide resistance were found in insect vectors of human diseases, the widespread use of DDT, lindane, and dieldrin in vector control programs led to establishment by 1970 of insecticide resistance in 118 pests of crop, forest, and stored products versus 106 pests of humans or animals (Brown 1971). By 1980 resistance was established in 260 agricultural pests as compared to 168 pests of humans and animals (Georghiou 1981). These figures probably understate the severity of the resistance problems worldwide because the susceptibility of many insect pest species has not been studied, is incompletely characterized, or is not reported adequately in the scientific literature. For example, the U.S. Insect Control Committee's visit to the People's Republic of China (NAS 1977) showed many examples of insecticide resistance not previously documented to the western world.

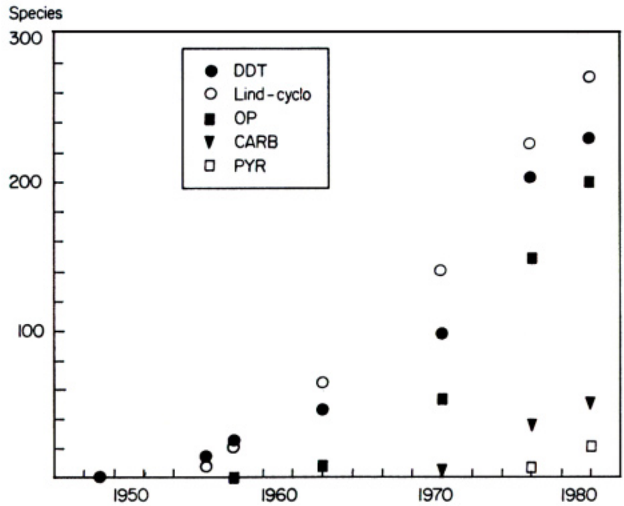
Insecticide resistance has been demonstrated in 16 orders of Arthropoda and its distribution has been recorded by Georghiou (1981): Acarina, 53 (12.4%); Anoplura, 6 (1.4%); Coleoptera, 64 (14.9%); Dermaptera, 1 (0.02%); Diptera, 153 (36.7%); Ephemeroptera, 2 (0.05%); Hemiptera, 20 (4.75); Homoptera, 42 (9.8%); Hymenoptera, 3 (0.07%); Lepidoptera, 64 (14.9%); Mallophaga, 2 (0.05%); Orthoptera, 3 (< 0.01%); Siphonoptera, 8 (1.9%); Thysanoptera. 7 (1.6%). These data reflect the relative number of pest species in the individual orders and the amount of insecticide pressure on them.

As each new class of insecticides was introduced and widely deployed against insect pests, the rate of development of resistant species followed an almost identical pattern (Fig. 1). The curves for rates of increase in resistant species are essentially exponential until high-level resistance or legal restrictions slow further usage. The curves are best characterized by the doubling times over the middle range. The data

Table 1. Development of arthropod pest resistance[a] to insecticides.

Year	Resistant species	Species (no.)				Reference
		2-stage	3-stage	4-stage	5-stage	
1938	7	0	0	0	0	Brown and Pal 1971
1948	14	1	0	0	0	Brown and Pal 1971
1954	25	18	3	0	0	Metcalf 1955
1969	224	42	23	4	0	Brown 1971
1975	364	70	44	22	7	Georghiou and Taylor 1977a)
1980	428	105	65	26	14	Georghiou 1981

[a]Resistance classes of insecticides as commonly defined are I. DDT, methoxychlor; II. BHC, lindane, cyclodienes, toxaphene; III. organophosphates; IV. carbamates; V. pyrethroids.



1. Rates of development of insect species resistance to DDT, lindane/cyclodienes, organophosphates (OP), carbamate (carb), and pyrethroid insecticides PYR.

show that doubling time for development of resistant species steadily decreased with the introduction of each type of insecticide (Tab1e 2) and that multiple resistance has disastrous effects.

Cross resistance and multiple resistance

Listing the exponential growth in numbers of insecticide-resistant pest species does not adequately describe the impact of resistance upon applied entomology. *Cross resistance* enables these resistant species to survive exposure to chemically related insecticides, e.g. DDT and methoxychlor, lindane and dieldrin, parathion and malathion, carbaryl and carbofuran, or permethrin and fenvalerate. Cross resistance is generally brought about by a common detoxication pathway or by a change in susceptibility to a common biochemical lesion. Far more serious is *multiple resis-*

Table 2. Approximate rates of development of insecticide-resistant insect species wordwide.

Resistant pests (no.)	Year resistance was attained[a]				
	DDT/ methoxychlor	Lindane/ cyclodienes	Organophosphates	Carbamates	Pyrethroids
5	1951	1954	1959	1971	1976
10	1952	1955	1962	1972	1979
20	1955	1956	1964	1974	1980
40	1960	1959	1968	1977	
80	1968	1965	1972		
160	1974	1971	1976		
Average doubling time	6.3 years	5.0 years	4.0 years	2.5 years	1 year

[a]Data from Brown and Pal (1971), Metcalf (1975), Brown (1971), Georghiou and Taylor (1977a), and Georghiou (1981).

tance (Table 1), which is now found in more than 100 important pest species that display resistance to a variety of insecticide classes with differing modes of action and detoxication pathways (Sawicki 1975). *Cross resistance* limits the choice of available insecticides, but *multiple resistance* reflects the past history of insecticide selection and precludes a return to those used previously. Both conditions seriously deplete insecticide resources (Metcalf 1982).

Multiple resistance is produced by several types of evolutionary mechanism arising through intense "natural selection." Altered acetyl-cholinesterase involves a biochemical alteration in the target-site enzyme of the organophosphate and carbamate insecticides so that entire categories of insecticides are no longer effective. This is the case with the cattle tick *B. microplus* in Australia (Schuntner and Thompson 1978) and with the green rice leafhopper *Nephotettix cincticeps* in Japan (Hama and Iwata 1978). Multiple resistance of this type is also found in the housefly and the red spider mite *Tetranychus urticae* (Oppenoorth and Welling 1976).

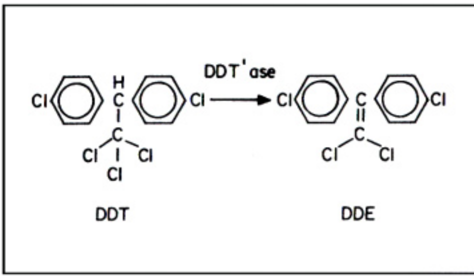
The kdr mechanism, an insensitivity of the nerve axon, that promotes multiple resistance between DDT and the pyrethroids is well known in the housefly and is also found in *Anopheles stephensi, A. gambiae,* and *A. quadrimaculatus;* in *Aedes aegypti;* and in *Culex tarsalis* (Oppenoorth and Welling 1976, Omer et al 1980). The kdr type of multiple resistance is also found in the bedbugs *Cimex* spp. and the cattle tick *Boophilus microplus,* and possibly in the lepidopterous pests *Spodoptera, Plutella,* and *Heliothis* (Sawicki 1980). Because of the very widespread nature of DDT resistance, documented in 229 pest species by 1980 (Georghiou 1981), this type of multiple resistance is particularly ominous.

A third mechanism of multiple resistance is that produced by hydrolytic esterases, whose specificity includes organophosphates, carbamates, and pyrethroids, as found in *M. persicae* and possibly in the green rice leafhopper *Nephotettix cincticeps* (Oppenoorth and Welling 1976, Sawicki 1980).

A fourth mechanism of multiple resistance is that produced by a generalized increase in the mixed function oxidase (MFO) enzymes that protect insects from xenobiotic compounds and therefore prevent a variety of insecticide molecules from reaching their target sites (Oppenoorth and Welling 1976).

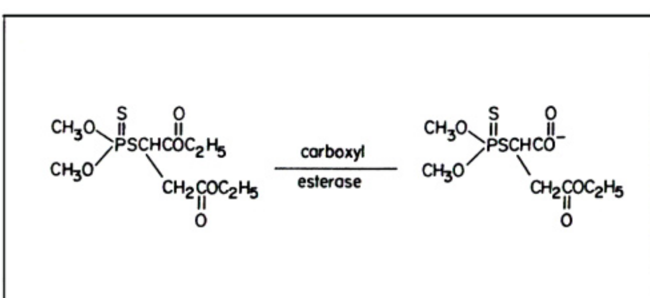
Multiple resistance is now very widely distributed in at least 44 families of 10 orders (Georghiou and Taylor 1977, Georghiou 1981). Pests that by 1980 had developed almost complete multiple resistance to the principal classes of insecticides (a) DDT/methoxychlor, b) lindane/cyclodienes, c) organophosphates, d) carbamates, e) pyrethroids, and/or f) arsenicals) include *Anopheles sacharovi,* the German cockroach *Blattella germanica,* the ticks *Boophilus decoloratus* and *B. microplus,* the tobacco budworm *Heliothis virescens,* the Colorado potato beetle *Leptinotarsa decimlineata,* the green peach aphid *Myzus persicae,* the diamond back *Plutella xylostella,* the pear psylla *Psylla pyricola,* the red flour beetle *Tribolium castaneum,* the armyworms *Spodoptera frugiperda* and *S. littoralis,* the granary weevil *Sitaphilus granarius,* and the red spider mite *Tetranychus urticae* (Sawicki 1980, Georghiou 1981). The rapid rates of development of multiple resistance are shown in Table 2.

Insecticide resistance is believed to be the result of the natural selection of preadaptive mutants that possess genetically controlled mechanism for detoxication, target-site insensitivity, or other means of survival in the presence of the insecticide. For example, the major cause of DDT resistance in the housefly *Musca domestica* and the yellow fever mosquito *Aëdes aegypti* is the selection of individuals that produce high levels of a detoxication enzyme DDT'ase that attacks the a -H of the molecule of DDT, causing elimination of Cl and the formation of the insecticidally inactive product DDE [2,2-bis-(*p*-chlorophenyl)-1, 1-dichloroethylene] (Oppenoorth and Welling 1976).



DDT'ase is readily inhibited by a variety of DDT analogues such as chlorfenethol [1,1-bis-(*p*-chlorophenyl)+thanol], and these compounds can serve as effective synergists for DDT to restore activity against the DDT-resistant housefly. This synergistic action of such DDT analogues as chlorfenetho, 1, 1-bis-(*p*-chlorophenyl)-2,2,2-trifluoroethanol, 1, 1-bis-(*p*-chlorophenyl)-ethane, bis-(*p*-chlorophenyl)-chloromethane, and *p, p*'-dichlorobenzenesulfanilide demonstrates conclusively that DDT'ase activity is the specific biochemical cause of a major type of DDT resistance. Genetic control of DDT'ase activity in the housefly results from a single gene on chromosome 2 (Brown and Pal 1971).

Another informative example of the biochemical basis for insecticide resistance is the selective detoxication of malathion by carboxylesterase in resistant races of the mosquito *Culex tarsalis,* the housefly, the green rice leafhopper *Nephotettix cincticeps,* and other species. The carboxylesterase selectively attacks one of the carboxy-



ethyl groups of malathion, converting it to the nontoxic malathion monocarboxylic acid. The carboxylesterase can be inhibited by the P=0 oxidation product of the insecticide EPN (*0*-ethyl *0*-*p*-nitrophenyl phenylphosphonothionate), and EPN has been used as a synergist for malathion resistant *C. tarsalis,* which confirms the mechanism of resistance (Oppenoorth and Welling 1976).

It should be emphasized that there are many other biochemical processes responsible for insect resistance to various insecticides. It appears that almost any biochemical mechanism affecting xenobiotic molecules will be utilized as an insecticide resistance mechanism if enough selection pressure is placed upon the pest species. Furthermore, as a variety of insecticides are utilized in insect control, successive levels of biochemical resistance can be superimposed in the individual species to give very complicated resistance patterns and mechanisms (Oppenoorth and Welling 1976).

The genetics of insecticide resistance, which is too complex to discuss here, has been extensively reviewed by Oppenoorth (1965) and Brown and Pal (1971).

The gravity of multiple resistance to current insect control practices relying exclusively on insecticides cannot be overstated. For example, both altered acetylcholinesterase and kdr are found in the cattle tick *B. microplus*. The crucial question today is not "to what insecticides are these pests resistant" but rather "to what insecticides are they susceptible" (Keiding 1977, Sawicki 1975). The true dimensions of the resistance problems are not known because precise data on the primitive susceptibility levels of many important pests are lacking (Chio et al 1976). No group of insecticides is "resistance proof" and multiple resistance can be present before new insecticides are introduced commercially (Attia and Hamilton 1978, El-Sebae 1977, Georghiou et al 1975, Keiding 1977).

Persistence of resistance genes

Once selected for, resistance genes have virtually limitless persistence in wild insect populations. Although the gene frequency of a specific resistance allele may decrease upon removal of insecticide pressure, the persistance of a changed background of residual inheritance in the genome causes the strain to regain its resistance as soon as the insecticide is reapplied (Brown 1977). Genes for DDT and cyclodiene resistance in Danish houseflies have persisted for more than 20 years; these insecticides again became ineffective within 2 months after reapplication. Genes for resistance to diazinon and dimethoate also have shown great persistence (Keiding 1977). Multiple resistance in the cotton leafworm in Egypt has shown no signs of regression over an 11-year period (El-Sebae 1977). These factors prevent the successful long-term reuse of any insecticide in insect populations with resistance alleles, even though the initial resistance has apparently reverted to full susceptibility (Brown 1977, Georghiou and Taylor 1977, Keiding 1977).

RESURGENCE OF PESTS AND POTENTIAL PESTS

The complexity of the ecological relationships regulating population densities of insect pests was articulated by Forbes (1880) a century ago. The development of pesticides provided exceptionally effective tools for disrupting the food webs linking crop plants, herbivores, and their predators and parasites. Pickett (1949) and coworkers in Nova Scotia apple orchards demonstrated 30 years ago that the flotation sulfur fungicides used to control apple scab produced marked destruction of the chalcid parasite *Aphelinus mytilaspidis* and of the mite predator *Hemisarcoptes malus,* which regulates populations of oyster shell scale *Lepidosaphes ulmi.*

Thus, over a 15-year period, the latter became an increasingly severe pest in orchards sprayed with sulfur. Biological balance was restored by substituting copper fungicides that did not adversely affect the natural enemies.

The proliferation of new broad-spectrum insecticides after 1946 and the steady rise in their use greatly increased the occurrences of resurgence, and Ripper (1956) tabulated more than 50 species of phytophagous arthropods whose populations had resurged after treatments with such diverse insecticides as calcium arsenate, cryolite, DDT, BHC, aldrin, toxaphene, and parathion. Two types of resurgences were characterized: a) pest populations, which were initially suppressed by the insecticide application, rebounded to excessive levels within a relatively short time; and b) potential pests, i.e. economically unimportant nontarget species, developed into serious pests after insecticide was applied to control other target species. For both types of resurgence there is overwhelming evidence of a negative correlation between the population density of the resurging species and of their natural enemies (Reynolds 1971). The cabbage aphid *Brevicoryne brassicae,* when first sprayed commercially with para-oxon, provided a good example of a resurgent pest. Although the initial kill was very high, the concomitant destruction of the aphid's natural enemies resulted within 2 weeks in the most enormous cabbage aphid outbreak ever seen in England. The first use of DDT sprays in California citrus orchards in 1946–47 to control citricola scale *Coccus pseudomagnoliarum* and other pests resulted in the resurgence of a secondary pest, the rarely seen cottony cushion scale *Icerya purchasi.* DDT almost eliminated its specific predator *Rodolia cardinalis* and within a few months the cottony cushion scale became so abundant that the citrus trees dripped with honeydew. Total defoliation and loss of crop were frequent. Ultimately thousands of acres of trees were damaged and DDT became anathema to citrus growers (Ripper 1956).

The use of the modern broad-spectrum insecticides DDT, parathion, carbaryl, and their relatives in deciduous and citrus fruit orchards and on cotton and other crops resulted in drastic changes in the populations of phytophagous mites. These were rarely abundant enough in the period before 1956 to require pesticide applications and were kept in biological balance by effective natural enemies, including the predaceous mites *Typhlodromus* spp. and *Amblyseius* spp., the coccinellidae predator *Stethorus,* and the predaceous thrips *Scolothrips.* There is overwhelming evidence that the use of the broad-spectrum pesticides is responsible for the worldwide outbreaks of red spider mites since the introduction of DDT (Ripper 1956, McMurtry et al 1970).

Today, the usage of broad-spectrum pesticides has almost inevitably been followed by pest resistance, pest resurgence, and outbreaks of secondary pests (Georghiou and Taylor 1977a,b; Reynolds 1971). An inventory of the 25 most serious insect pests of agriculture in California, each judged to cause more than $1 million in damage in 1970, disclosed that 17 are resistant to one or more classes of insecticides, and 24 are either secondary pest outbreaks or pest resurgences aggravated by the use of insecticides (Luck et al 1977). The widespread development of these "man-made" or entomologenic pest outbreaks is one of the most serious indictments of our present-day pest control technology (Luck et al 1977, Van den Bosch 1978).

Overdependence on broad-spectrum insecticides can be catastrophic, as revealed in the following examples.

Cotton in Nicaragua

Cotton cultivation in Nicaragua flourished during the 1950s and reached a peak in 1965, but during the following 5 years production decreased at an annual rate of 15.9%. The primary cause of this crisis was the failure of insect pest control that was based on broad-spectrum insecticides. Rapidly developing resistance resulted in explosive outbreaks of *Heliothis zea* and *Spodoptera sunia,* which became almost impossible to control. The whitefly *Bemisia tabaci* became resistant to the mixture of toxaphene-DDT-methyl parathion in common use. The false pink bollworm *Sacadodes pyradis* almost disappeared and the boll-weevil *Anthonomus grandis* became a pest. Secondary pests such as *Spodoptera exigua* and *Trichloplusia ni,* and the plant bugs *Creontiades* spp. caused severe damage. The conventional remedy of higher dosages and more frequent applications was applied and treatments averaged 25-30 per season and in single fields reached more than 50, sometimes with 5 different insecticides in a single application. The cost of insect control reached 26-40% of total production costs. Among the unfortunate environmental consequences were thousands of cases of insecticide poisoning and hundreds of deaths, the highest recorded residues of DDT in human milk, and a resurgence in malaria transmission because of resistance to cotton insecticides developed in the vector *Anopheles albimanus* (Brader 1979, Vaughan and Gladys 1977).

Deciduous fruit in China

During the 1950s spraying apples with DDT gave good control of the leafrollers *Choristoneura lonicellana, Leucoptera citella,* and *Illiberis pruni.* However, use of DDT nearly eliminated beneficial insects such as *Coccinella septapunctata, Scolothrips* sp., *Stethorus punctillum,* and hymenopterous parasites of scale insects. Red spider mites *Tetranchus viennensis* and *Bryobia praetiosa* became the most severe pests and they rapidly developed resistance to parathion and to the specific acaricides used to control them so that as many as 10 treatments a season were required. The leafroller *L. citella* became rampant causing severe leaf damage and drop. On pears, DDT and parathion were used to control the oriental fruit moth *Grapholitha molesta,* but they also killed the natural enemies of the San José scale *Aspidiotus perniciosus,* and caused severe scale outbreaks and extensive loss of trees. The usage of insecticides on deciduous fruits increased until insecticide cost was 25% that of fruit productions (NAS 1977).

Rice in Southeast Asia

During the 1950s DDT and BHC were applied to control the rice stem borer *Chilo suppressalis* and the paddy borer *Tryporyza incertulas.* These broad-spectrum insecticides decimated the natural enemies of the leafhoppers and planthoppers, especially *Lycosa* spp. spiders and hymenopterous parasites such as *Trichogramma.* The green rice leafhopper *Nephotettix cincticeps* and the planthoppers *Nilaparvata lugens, Sogatella furcifera,* and *Laodelphax striatellus* became important secondary pests, especially as vectors of rice virus diseases. Parathion and methyl parathion were introduced for their control. Increasing numbers of applications were made until BHC (in 1969) and parathion (in 1971) were banned in Japan. The problem worsened with the introduction of the new high-yielding japonica rice varieties of the "green revolution," which were highly fertilizer dependent and lacked the insect pest resistance genes of the indica varieties. Use of these varieties often increased insect pest attacks and required increased insecticide applications. As a result during 1950-74 the use of insecticides increased 33-fold, but yield rose only 1.5-fold despite the new varieties and high fertilization. The green rice leafhopper and the plant-hoppers developed very high levels of multiple resistance to almost all available organophosphorus and carbamate insecticides. From four to seven applications of insecticides were required during 1969-71 in contrast to one to two in 1965. Other secondary pests of rice production have become important, including the rice leafroller *Cnaphalocrocis medinalis,* the rice gall midge *Orseolia oryzae,* and the rice whorl maggot *Hydrella philippina.* Presently the multiresistant rice leafhopper and brown planthopper are almost uncontrollable in much of Southeast Asia (Kiritani 1979). Insecticide resistance in insect pests of rice has been demonstrated in 13 insect pests of 5 orders (Table 3).

These examples demonstrate that both pest resurgences and secondary pest development occur most often on such crops as cotton, rice, citrus, deciduous fruits, vegetables, and ornamentals when the environment is continually treated with insecticides (Luck et al 1977, Reynolds 1971). The almost universal "cure" has been to increase the frequency and amount of insecticides applied and, when control becomes inadequate, to switch to another insecticide or combination of insecticides. This practice inevitably leads to the pesticide treadmill (Van den Bosch 1978). The present status of cotton insect control in Egypt demonstrates the futility of this approach. The cotton leafworm *Spodoptera littoralis* is a rampant secondary pest which, after 6 years of toxaphene applications in 1961, attained epidemic population levels. Between 1961 and 1975 more than 369 million kg (ai) of the following insecticides were applied to Egyptian cotton to control the cotton leafworm, the spiny bollworm *Erias insulana,* and the pink bollworm *Pectinophora gossypiella:* toxaphene, carbaryl, trichlorfon, endrin, DDT, lindane, methyl parathion, feni-trothion, monocrotophos, dicrotophos, phospholan, mephosfolan, leptophos, chlorpyrifos, stirofos, methamidophos, azinphos methyl, methomyl, diflubenzuron. Mixtures of these insecticides were used as well. Now the cotton leafworm exhibits multiple resistance to virtually every insecticide, and resistance levels have shown no sign of reversion over more than 10 years. As a result no new insecticide has remained effective for more than 2-4 years (El-Sebae 1977).

Experience from many parts of the world has demonstrated that resurgence and the development of secondary pests are inextricably linked and that these disturbances of pest ecosystems cannot be corrected over the long run by continued and exclusive application of broad-spectrum insecticides. The obvious solution is to implement integrated pest management (IPM) programs that institute ecologically sound and multicomponent suppression on pest populations.

INTEGRATED PEST MANAGEMENT

Total reliance on broad-spectrum insecticides, the insect control strategy of the past 35 years, is a disastrous solution to the long-term problems of insect control. The

Table 3. Insecticide resistance in pests of rice.[a]

Coleoptera		
Lissorhoptrus oryzaephilus		
BHC/cyclodienes		
aldrin, dieldrin	USA	Rolston et al (1965)
heptachlor	USA	Brown (1971)
Diptera		
Agromyza oryzae		
DDT	Japan	Asakawa (1975)
BHC/cyclodienes		
lindane	Japan	Asakawa (1975)
Hemiptera		
Leptocorisa acuta		
BHC/cyclodienes		
endrin, isodrin, toxaphene	Thailand	Chakrabandhu (1965)
Organophosphates		
diazinon, malathion, parathion, TEPP	Thailand	Chakrabandhu (1965)
Leptocorisa varicornis		
methoxychlor	Thailand	Chakrabandhu (1965)
BHC/cyclodienes		
aldrin, dieldrin	Thailand	Chakrabandhu (1965)
Scotinophora lurida		
BHC/cyclodienes		
lindane/BHC	Taiwan	Ma (1965)
Homoptera		
Delphacodes striatella		
BHC/cyclodienes		
lindane, BHC	Japan	Shiino (1961)
Inazuma dorsalis		
DDT	Taiwan	Ma (1965)
Laodelphax striatellus		
BHC/cyclodienes		
lindane, BHC	Japan	Kimura (1973)
Organophosphates		
diazinon	Japan	Kassai & Ozaki (1966)
fenitrothion	Japan	Kimura (1965)
fenthion	Japan	Ozaki & Kassai (1971)
malathion	Japan	Kimura (1965)
	South Korea	Choi & Song (1973)
methyl parathion	Japan	Kassai & Ozaki (1966)
phenthoate	Japan	Kimura (1965)
Carbamates		
carbaryl, MTMC	Japan	Kiritani (1974)
propoxur	Japan	Iwata & Hama (1972)
Nephotettix bipunctatus		
DDT	Vietnam	FAO (1969)
Nephotettix cincticeps		
Organophosphates		
dimethoate, fenitrothion, EPN, phenthoate	Japan	Ozaki & Kurosu (1967)
parathion, methyl parathion	Japan, Taiwan	Ozaki & Kurosu (1967), Ku & Wang (1976)
fenthion	South Korea	Lee & Koo (1972)
diazinon, salithion	Japan	Ozaki & Kassai (1970)

Table 3 continued

malathion	China	Chin (1979)
	Japan	Kojima et al (1963)
	Taiwan	Ku & Wang (1976)
vamidothion	Taiwan	Sun (1978)
Carbamates		
isocarb, 'Bassa', MTMC, methomyl	Japan	Moriya (1974)
carbaryl, propoxur	Japan	Iwata & Hama (1972)
Nilaparvata lugens		
DDT	Vietnam	Anon. (1974)
BHC/cyclodienes		
aldrin, dieldrin	Fiji	Hinckley (1968)
	Taiwan	Fukaya (1968)
lindane, BHC	Fiji	Hinckley (1968)
	Japan	Kimura et al (1973)
	Taiwan	Fukaya (1968)
Organophosphates		
diazinon	Philippines	Anon. (1969)
	Vietnam	Anon. (1974)
EPN	Japan	Kiritani (1969)
fenitrothion, fenthion	Japan	Ozaki (1978)
parathion	Japan	Ozaki (1978)
	Taiwan	Ku et al (1977)
methyl parathion	Vietnam	Anon. (1974)
malathion	Japan	Ozaki (1978)
	Taiwan	Ku et al (1977)
	Vietnam	Anon. (1974)
monocrotophos	Guadalcanal	Stapley (1974)
Carbamates		
carbaryl	Japan	Ozaki (1978)
isoprocarb	Taiwan	Lin et al (1979)
MTMC	Taiwan	Lin et al (1979)
	Japan	Ozaki (1978)
Lepidoptera		
Chilo suppressalis		
BHC/cyclodienes		
lindane, BHC	Japan	Asakawa (1975)
	Taiwan	Ma (1965)
Organophosphates		
diazinon	Japan	Ozaki (1974)
	South Korea	Lee & Yoo (1972)
EPN	Japan	Ozaki (1974)
	Taiwan	Ma (1965)
fenitrothion, fenthion	Japan	Ozaki (1970)
	South Korea	Lee & Yoo (1972)
parathion, trichlorfon	Japan	Ozaki (1962)
Tryporyza incertulas		
BHC/cyclodienes		
lindane, BHC	China	Chin (1979)
Organophosphates		
parathion	China	Chin (1979)
	Taiwan	Ma (1965)
	China	Chin (1979)
	Taiwan	Ma (1965)

[a]Data from Georghiou (1981).

frequency of insect pest resistance, pest resurgences, and outbreaks of secondary pests provide a strong argument against it (Luck et al 1977). Furthermore, the exponentially rising costs both of current insecticides and of new insecticide development make it essential to turn from routine serial applications to judicious use. Finally, increasing public concern about the hazards of pesticides to human health, to nontarget organisms and to the quality of the environment can be answered only through decisive changes in both the quantity and the methods of insecticide use in agriculture.

The misuse of insecticides has been the major factor in the rapid growth of interest in IPM. IPM seeks to minimize the disadvantages of insecticides and maximize their advantages (Meltcalf and Luckmann 1982) by encouraging ecologically sound approaches to insect pest control. As Newsom (1978) pointed out, the most selective way to use an insecticide may be not to apply it: doing nothing is a valid IPM alternative. In IPM programs, the need for insecticide use must be well documented and the way in which insecticides are to be used, the quantities applied, and the nature of the insecticides selected must be thoroughly examined (Metcalf and Luckmann 1982).

Insecticide management

This concept is concerned with the safe, efficient, and economical handling of insecticides from the time of manufacture to final utilization and disposal. It concerns pesticide residues in food and in the environment and their impact on man (Davies 1977, Smith 1976, Watson and Brown 1977). Implicit in insecticide management is a thorough consideration of the benefit vs. risk of the purposeful contamination of the environment that the application of an insecticide represents (Metcalf and Luckmann 1982).

Principles of pesticide management governing the usage of insecticides in IPM are a) observe realistic economic thresholds, b) improve timing of application, c) improve application methods, d) reduce application rates, e) use pesticides that are least toxic to important natural enemies, and f) apply selective insecticides in lieu of broad-spectrum biocides.

Economic thresholds

As we have seen, the heavier the use of insecticides on a crop, such as cotton, the greater the chances of disaster (El-Sebae 1977, Luck et al 1977, Reynolds 1971, Vaughan and Gladys 1977). Realistic economic thresholds (Metcalf and Luckmann 1982) that relate crop damage quantitatively to pest population densities are the keystones of IPM programs developed to delay insecticide treatments until there is every reason to believe that natural enemies, diseases, and cultural practices cannot prevent economic damage. Observance of realistic economic thresholds can dramatically improve the benefit-cost of insecticide use. In Illinois in 1974-75, 57-67% of the total maize acreage was routinely treated with soil insecticides at planting time to prevent damage by corn rootworms (*Diahrotica* spp.), yet careful study showed that only 11-19% of the maize acreage had rootworm populations above the economic threshold (Luckmann 1978). In 1976 >30 million acres of the U.S. maize crop were treated with soil insecticides (USDA 1978b). With treatment costs ranging from $10 to $20 per acre, the potential savings from observing the economic threshold approach was US$500 million. And this says nothing about effects on insecticide resistance and environmental quality.

Recent appreciation of the soybean's remarkable tolerance for insect attack resulted in the establishment of realistic economic thresholds for IPM of soybean pests 3- to 10-fold higher than those used for exclusive chemical control. The application of these economic thresholds is the principal factor preventing the U.S. soybean crop from becoming a pesticide treadmill (Newsom 1978). The IPM technology has been applied with great success to the seriously overtreated soybean crop of Brazil; insecticide treatment reductions up to 93% resulted in no significant change in yields (Kogan et al 1977), and the program has been extended nationally to >5 million acres.

Application methods

It has been shown repeatedly that only about 10-20% of insecticides broadcast as dusts and 25-50% of those sprayed are deposited on plant surfaces and less than 1% reach the target insect. Any improvement in reaching only the target insect will improve the survival of natural enemies. Low-volume spraying is generally less injurious than high-volume spraying (Ripper 1956). Granular insecticides are substantially more selective than sprays, decidedly less hazardous to the applicator, and generally reduce the dosage required, e.g., soil applications of carbofuran, fonofos, phorate, or terbufos to control corn rootworm are less disturbing to the ecosystem than aerial sprays of carbaryl to control the adults. Seed treatments, especially with systemic insecticides, provide minimal dosages and high ecological selectivity. Protein hydrolysate bait spray with malathion for control of the Mediterranean fruitfly *Ceratitis capitata* is more ecologically selective than conventional broad coverage. The direct treatment of maize silks to control the corn earworm *Heliothis zea* is ecologically much to be preferred to broad coverage applications.

It is important to provide refugia for the survival of beneficial insect populations in the ecosystem. Spot spraying is ecologically preferable to general spraying and is widely practiced in IPM programs in China (NAS 1977). Biological control of scale insects in California citrus orchards has greatly improved through alternate spraying of the tree rows at 6-month intervals (Ripper 1956). Strip spraying of row crops can provide similar refugia for natural enemies.

Improved timing

The utilization of the principle of improved timing is an important step in the transition between the pesticide treadmill and IPM. The use of pheromone traps and light traps to time emergence of adult insects and, consequently, egg laying can markedly decrease the number of insecticide applications. In codling moth control, pheromone timing reduced the spray applications of azinphos methyl by one-third to one-half (Madsen and Vakenti 1973). Methyl parathion has been used successfully in an IPM program for the alfalfa weevil *Hypera postica* by timing the application in the early spring. This suppresses the initial weevil larval population when the principal parasite *Bathyplectes curculionis* is pupating and is not active in the field (Armbrust and Gyrisko 1975). Similarly, a single acaricide spray applied to the periphery of apple trees 3-5 weeks after bloom suppresses the European red mite that overwinters on the trunk and on grass and debris at the base (Meyer 1974). Applications of insecticides to orchards and field crops after bloom or in the evening when bees and other beneficial insects are not visiting blossoms is an important conservation measure.

Reduced application rate

Most spray schedules and label directions for insecticide use prescribe inflated dosages of insecticides. This is the result of the pervasive philosophy of pest eradication, e.g. 99+% control (Smith 1976). This strategy is open to serious criticism especially for IPM programs where natural enemy conservation is essential. Wigglesworth (1945) suggested that ultimately an insecticide which kills 50% of the pest insect and none of its predators may be more valuable than one which kills 95%, but at the same time eliminates its natural enemies. Van den Bosch and Stern (1962) showed that reduced dosages of broad-spectrum insecticides can increase selectivity by decreasing kills of natural enemies. Reynolds et al (1975) suggested that in integrated control systems, the relationships of pest abundance to crop damage are such that insecticide treatments giving 75% or lower mortality may be preferable to treatments giving 95% or higher mortality. These notions have led to the "dirty field" or "leave a pest residue" concept that stresses the importance of leaving substantial numbers of living target pests as host material to support natural enemy populations.

Adkisson (1971) showed that disulfoton used against the greenbug *Schizaphis graminum* was fully as effective over a 2-week period at 0.1 kg/ha as at 0.28 kg, and parathion at 0.1 kg/ ha was almost as effective as the recommended dosage of 0.56 kg. In codling moth control, Madsen and Williams (1968) obtained nearly as effective control on apples at 2.80 kg/ ha as at the standard dosage at 5.60 kg, and obtained reasonably effective control at 1.40 kg/ ha. A successful IPM program for European red mite uses reduced dosages of propargite or tricyclohexyltin hydroxide that decrease but do not eliminate the red spider mite populations so that the predatory mites *Amblyseius fallacis* have sufficient host material for survival (Croft 1975). In soybean culture it has been found that the use of minimum dosage rates of organophosphorus and carbamate insecticides, far less than those routinely used on cotton, can introduce a high degree of selectivity in favor of natural enemies. Application of these minimal dosages together with more realistic economic thresholds, made it possible to reduce the amount of insecticides required for control of soybean insects in 1976 by one-third to one-half that recommended in 1973 (Newsom 1978).

Selectivity of insecticides

Farsighted entomologists realized more than 30 years ago that certain insecticides were more compatible with survival of natural enemies than others and should be favored for use (Pickett 1949). Thus pesticide management began to take form and substance. Unfortunately, its outlines were obscured by "eradication" programs, the mad scramble to market any new product that killed insects, and rapidly developing pest resistance. Nevertheless a certain amount of progress has been made. There is critical need for detailed laboratory and field studies of the selectivity of pesticides between pest and natural enemies. Examples of the importance of this subject can be found in the laboratory studies of Bartlett (1958) and Jeppson et al (l975) and in field evaluations by Stern et al (1960) and Lingren and Ridgway (1967).

PEST RESISTANCE

The continued selection of races of insect pests resistant to insecticides is the direct result of exclusive reliance on chemicals for insect control. Insecticide resistance is not only a disaster to present methods of insect control, it also prejudices the usefulness of some of the best insecticides in future IPM programs. The economic impact of even moderate levels of resistance (2-5X) is much more severe with the newer pyrethroids and insect growth regulators ($110-880 kg) than it was with the organochlorines ($0.44-2.2/ kg). The concerted effect of the exponentially increasing costs of insecticide development, the dwindling rate of sale of new materials, and the demonstration of cross or multiple resistance to new classes of insecticides (almost before they are fully commercialized) make insect pest resistance the greatest single problem facing applied entomologists (Georghiou 1980). The only reasonable hope of delaying or avoiding pest resistance lies in IPM programs that decrease the frequency and intensity of genetic selection by reduced reliance upon insecticides and that use multiple tools for insect population control, such as natural enemies, insect diseases, cultural manipulations, and host plant resistance. Acting together. these measures can destroy most of the insecticide-selected resistant mutants before they can breed resistant progeny (Metcalf and Luckmann 1982, Georghiou and Taylor 1977a).

Authorities are in general agreement about practical measures to decrease the impact of insecticide resistance on both agriculture and public health (Brown 1977, Georghiou and Taylor 1977b, Keiding 1977, Georghiou 1980, Metcalf 1980). These measures are to reduce selection pressure and to choose the optimal sequence of insecticides used.

Reduced selection pressure

This obvious countermeasure has had little application in most control programs. The following tactics are suggested: a) reduce frequency of insecticide treatments by treating only when necessary, b) reduce extent of treatments, c) avoid insecticides with prolonged environmental persistence and slow-release formulations, d) reduce use of residual treatments, e) avoid treatments that apply selection pressures on both larval and adult stages, and f) incorporate source reduction and nonchemical methods in control programs.

In essence these principles constitute a blueprint for IPM, and are dramatically opposed to practices in vogue today on crops such as cotton, maize, rice, and deciduous fruits. where economic thresholds are ignored, frequent and excessive treatments with broad-spectrum persistent insecticides are routinely and extensively made, slow release formulations are sought, both larvae and adults are often treated, and source reduction by sanitation and crop rotations is seldom practiced.

Management of insecticides

Countermeasures that relate specifically to the proper choice and use of insecticides can be decisive factors in coping with pest resistance, or more realistically, in preserving pest susceptibility. Systematic application is necessary:

- Monitor insect pest populations so that primitive susceptibility levels are understood and early detection of specific resistance is possible (Brown 1977). This should be done using standardized and widely accepted test methods for resistance. FAO and WHO have taken the lead in this area (Waterhouse 1977, WHO 1976).
- Avoid the use of insecticide mixtures as they generally result in the simultaneous development of resistance (each compound seems to develop the residual inheritance of the supporting genome for resistance in the other).
- Extend the useful life of a satisfactory insecticide as long as possible, but monitor susceptibility and replace the insecticide before control fails.
- Choose a sequence of suitable alternative insecticides based on genetic considerations of cross resistance and multiple resistance (Brown 1977, Keiding 1977, Sawicki 1975).

A remedial insecticide chosen from cross resistance studies should always be available, e.g. in WHO vector control programs methyl chlorpyrifos for temephos in larval control of the *Simulium* vector of onchocerciasis; chlorpyrifos for fenthion in larval control of *Culex fatigans,* the vector of filariasis; or carbaryl plus piperonyl butoxide for malathion in the control of *Pediculus humanus,* the vector of endemic typhus. In agriculture this has occurred successfully with azinphos methyl as a replacement for DDT in codling moth control, diazinon as a replacement for aldrin in corn rootworm control, and with permethrin and fenvalerate as replacements for methyl parathion for *Heliothis* control. Detailed and long-term study of housefly resistance in Denmark has demonstrated that the incorrect choice of alternatives is likely to be most damaging for future control (Keiding 1977, Sawicki 1975). Here are factors to consider:

- First use insecticides with simple one-factor resistance and limited cross resistance, e.g. malathion.
- Avoid insecticides with complicated multiplicate resistance, e.g. diazinon.
- Avoid or delay use of insecticides that act as effective selectors of resistance for other insecticides, e.g. dimethoate for pyrethroids.
- Exploit alternative treatments with insecticides without common major R factors, and change insecticides before resistance develops.

This latter point is particularly important when following DDT resistance due to the kdr mechanism with synthetic pyrethroids.

In summary, pesticide management strategies that will extend the lifetimes of the insecticides now available so that they may be incorporated in IPM programs are the most crucial requirement. Strategies for delaying resistance involve the rotation or the joint use of insecticides (Georghiou 1980). In Chinese fruit orchards, for example, three to five different insecticides are carefully rotated to delay the onset of resistance (NAS 1977). Such strategies will involve biological wisdom, societal cooperation, and economic constraints that can be achieved in large public health programs but that will be much more difficult to implement in agriculture (Elliott et al 1978).

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DISCUSSION

KENMORE: Please list the first two or three steps we must take to establish appropriate early warning systems for insecticide resistance. This is especially critical now that Taiwan, China, has slid far on the exponential curve of resistance with time, and the IRRI farm is at midcurve.

METCALF: 1) Early detection of resistance through precise dosage-mortality data to monitor the position (LD_{50}) and slope of dosage-mortality response. 2) Establish the levels of primitive susceptibility to a variety of insecticides of the pest from areas where pesticides have not been used extensively, or if this is impracticable, study closely related species that are not of economic importance. 3) Discontinue the use of specific insecticides whenever the above parameters indicate that a change in susceptibility is occurring.

PERFECT: What are the implications of intensive insecticide use in restricted areas such as experimental stations, on the frequency of genes for resistance in the general population?

METCALF: The presence of a concentrated source of R-genes in a pest population poses a threat to any area where the pest can migrate or be transported, if there are selective agents in the new environment (that is, intensive insecticide treatments give the R-genes an advantage in survival and recombination). There are a number of examples known where R-pests have migrated or colonized new areas. For example, malathion-resistant stored grain pests are found at most major ports. Resistant southern corn rootworms migrate up the Mississippi Valley, USA, every spring. Resistant rice leafhoppers and planthoppers seem to have migrated throughout Southeast Asia. This clearly is a potentially serious problem in areas where selection pressures from heavy pesticide use prevail.

HEINRICHS: Do low rates with low percentages of mortality or high rates with high percentages of mortality cause a faster occurrence of resistance to insecticides?

METCALF: Resistance is the result of natural selection of preexisting R-mutants. Therefore, the more intensive the selection pressure, the more rapid the development of resistance, because the opportunities for gene recombination are increased.

MOCHIDA: You said that quick development of resistance to insecticide can be avoided by not using mixtures of insecticides. Is that always true? Are there any exceptions?

METCALF: It is impossible to be categorical about the effects of the use of mixtures. As multiple resistance to a variety of insecticides is imprinted in pest populations, the likelihood of mixtures working satisfactorily is expected to decrease. A number of laboratory and field studies have shown that pests exposed to mixtures eventually develop resistance to both components, for example, DDT + DMC (chlorfenethol) or pyrethroids + piperonyl butuxide. The work reported by Nagata and Mochida (this conference) on rice leafhopper resistance to mixtures of carbamates and organophosphates or carbaryl plus N-propylcarbaryl indicate not only initial effectiveness but also slow development of resistance to the mixture. The use of a specific mixture can probably be justified if its components are chosen from scientific considerations of uncorrelated modes of action, interference with detoxication systems, and genetic considerations showing that no alternative pathways for resistance exist in the pest population. However, if there is a multiple-resistance component such as altered acetylcholinesterase for a mixture of organophosphorus and carbamate insecticides; or the mechanism of altered nerve axon for a mixture of pyrethroid and DDT; the use of such mixture will, in the long term, worsen the resistance situation. The use of alternate applications of carefully chosen insecticides, keeping in mind the above considerations, seems to be the preferred approach. It simplifies formulation and residue persistence problems (it is very difficult to find two components of a mixture that degrade at the same rate) and the components of alternate treatment programs can be varied, when necessary, if resistance develops.

This complex subject requires much more research.

SADJI: You suggest avoiding insecticides with slow-release formulations to reduce selection pressure. Does this suggestion include granular formulations of insecticides?

METCALF: Slow release means long persistence, and most authorities see long persistence as favoring selection for resistance. Ordinary granular formulations on clays or ground plant material are not classified as slow-release formulations. Slow-release formulations include micropellets, coated granules, hollow fibers, plasticized products, encapsulated formulations, etc.

SANCHEZ: Insecticide resistance is a serious problem. It is particularly grave in the case of the diamond-backed moth (*Plutella xylostella*), which developed resistance to just about every insecticide that has been used against it, except mevinphos, which is still effective after 25-30 years of continuous use. How would you explain this?

METCALF: Resistance depends on preadoptive, genetically controlled mechanisms that favor survival. These mechanisms are caused by mutations in the population. It would appear that such a mutation has not occurred in the population of *P. xylostella* you described. It would be interesting to determine if *P. xylostella* anywhere in the world is resistant to mevinphos. I have the impression that such resistance has been observed in Taiwan, China. There are examples of this sort with other pests, for example, citrus red scale *Aonidiella aurantii* has not developed resistance to parathion in California over 30 years of use. But, in S. Africa, this same pest has become highly resistant to parathion. The reason obviously lies in the differing genetic make-ups of the populations in the two areas. Examples of this sort need further intensive study.

RENDELL: Would you comment on the development of resistance in natural enemy populations?

METCALF: Natural enemy populations can develop resistance, for example, Phytoseiidae mites in deciduous fruit orchards, resistant to azinphos methyl (Guthion), are now deliberately introduced and used in orchard IPM for European red mite. Many other examples must exist but few have been identified. The general impression seems to be that beneficial organisms develop resistance much more slowly than primary pests fora variety of reasons, such as longer life cycles, as with spiders and predators.

DEVELOPMENT OF INSECTICIDE RESISTANCE AND TACTICS FOR PREVENTION

T. Nagata and O. Mochida

Five species of rice insect pests have been reported resistant to insecticides in Japan. They are green Ieafhopper, striped stem borer, small brown planthopper, brown planthopper, and rice leaf beetle. The first four species are discussed in detail, based on data from Japan; Taiwan, China; and Korea.

Japan was the first Asian country to introduce synthetic organic insecticides to control rice insect pests, and has used insecticides extensively. This has encouraged insecticide resistance and destroyed various nontarget insect species.

Insecticide resistance in other rice growing countries is still rare. A few recent reports of mild resistance have concentrated on rice leafhoppers and planthoppers. Green leafhopper (GLH) *Nephotettix cincticeps* (Ku and Wang 1975, Ku et al 1976) and brown planthopper (BPH) *Nilaparvata lugens* (Lin et al 1979) have been reported resistant in Taiwan, as have small brown planthopper (SBPH) *Laodelphax striatellus* and GLH in Korea (Choi et al 1975, Song et al 1976), GLH *Nephotettix virescens* in Indonesia (Merthakota and Sutrisno 1982), BPH and whitebacked planthopper (WBPH) *Sogatella furcifera* in Sri Lanka (Wickremasinghe and Elikawela 1982), and BPH in the Philippines (Mochida and Basilio 1983). Most of these reports lack sufficient laboratory data, but there is strong evidence that the rice water weevil *Lissorhoptrus oryzophilus* developed high levels of resistance to aldrin in early 1960s in the USA (Rolston et al 1965), and the paddy bug *Leptocorisa varicornis* has been reported to have BHC resistance in Sri Lanka (Wickremasinghe and Elikawela 1982).

In this article we discuss some typical cases of insecticide resistance in Japan and briefly refer to problems in other Asian countries.

STATUS OF INSECTICIDE RESISTANCE IN RICE INSECT PESTS

Green leafhopper (GLH) *Nephotettix cincticeps*

Resistance in foliar application. GLH insecticide resistance is the most serious among rice insect pests. The most detailed knowledge about GLH resistance has been compiled in Japan.

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Malathion and parathion were the first insecticides extensively used against GLH. Malathion use began in 1953 and resistance was first reported in 1960-61 at Kochi prefecture, where double-cropped rice received frequent insecticide applications. Methyl parathion applications to control SB and GLH began in 1951. Resistance developed in 1962. Resistance to these insecticides spread rapidly throughout southern Japan. Distribution of resistant GLH populations was carefully mapped at the village level using standard bioassay techniques.

Malathion and parathion (both organophosphates) were replaced by carbamate insecticides because GLH showed cross resistance to other organophosphates too. Carbaryl, the first carbamate, was commercialized in 1959 and many other carbamates were developed in the 1960s: CPMC and propoxur in 1964; MPMC, MIPC, MTMC in 1967; and BPMC and XMC in 1969.

In 1969 carbamate-resistant GLH was found in Ehime prefecture in central Japan, where farmers had used carbaryl and phenylcarbamates for 7 years. By 1975 resistant GLH populations occupied most of western Japan. They had nearly 100-fold resistance to propoxur and BPMC and a high level of resistance to malathion (Table 1).

Diazinon, pyridaphenthion, propaphos, or a mixture of these with carbamates were used against carbamate-resistant GLH. Combinations of IBP + malathion, IBP + phenthoate, phenthoate + propoxur, and a mixture of N-propylcarbamate with N-methylcarbamate have also been found effective (Yamamoto et al 1978).

Insecticide-resistant GLH have been reported in Taiwan, China (Ku et al 1976), Korea (Song et al 1976), and China (Chen et al 1978), but resistance is generally low, except in Taiwan, where GLH-resistance almost equals that in Japan.

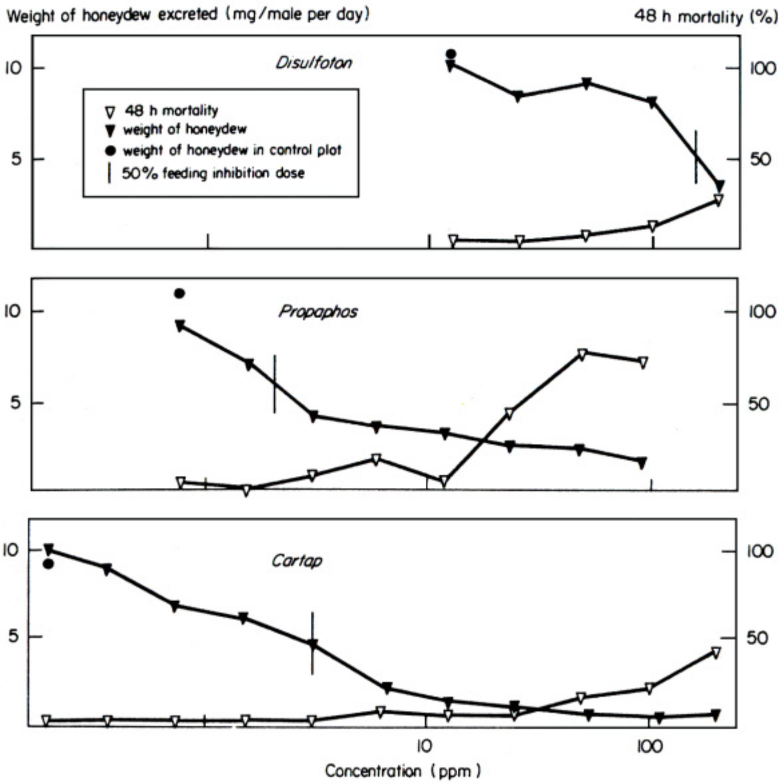
Resistance to granular treatments in nursery boxes. Mechanized transplanting, which allows more efficient insecticide applications for GLH control, has been used in Japan since 1969. Disulfoton, cartap, or propaphos granules are applied to nursery boxes immediately prior to transplanting to control GLH and SBPH. Cartap, propaphos, or propoxur are applied to control the rice leaf beetle *Oulema oryzae.*

Control is good because granules dissolve and release active ingredients slowly. Other advantages are labor savings because application coincides with transplanting, lower application rates, long period of persistence, and reduced effect on natural

Table 1. Development of insecticide resistance in rice green leafhopper *N. cincticeps* **in Shikoku, Japan.**

Insecticide	LD_{50} (µg/g)			
	Ehime prefecture [a] 1963	Ehime prefecture [a] 1970	Ehime prefecture [b] 1981	Koti prefecture [b] 1981
Malathion	12.41	330	143-570 [c]	292
Diazinon	8.99	11	44-53	37.2
Carbaryl	1.64	71	33-48	68.8
Propoxur	3.23	440	–	1396.8

[a] Iwata and Hama (1971). [b] Shikoku Experiment Station (1982). [c] LD_{50} range Of 2 local Populations.



1. Feeding inhibition by three systemic insecticides administered to green rice leafhopper *N. cincticeps* (resistant strain) through parafilm membrane (Nagata and Masuda 1981).

enemies. Disulfoton granules were widely used, beginning in 1973. After 1978 reduced field efficacy prompted replacement by propaphos or cartap granules.

Resistance to granular insecticides often is evaluated using topical application data that measure contact toxicity. Other bioassay methods should be used to evaluate oral intake of systemic insecticides by sapfeeding insects, especially as Nakasuji et al (1975) showed that rice dwarf is more effectively controlled by reducing insect transmitting ability than by population reduction. Sublethal doses of cartap have also been shown to be important to rice dwarf control (Kono et al 1975). Using a combination of these techniques will allow a more thorough evaluation of the nature of resistance relative to the control of insect-transmitted virus by systemic insecticides (Fig. 1).

Striped rice stem borer (SB) *Chilo suppressalis*

SB was the most destructive rice pest in Japan until 1952, when parathion became widely used. The first parathion resistance was reported at Kagawa prefecture in 1960. BHC 3% dust was used for SB control beginning in 1954. BHC broadcast granule use began in 1960. BHC resistance was reported in western Japan in the late 1960s.

BHC and parathion were replaced with diazinon, trichlorfon, fenthion, fenitrothion, or chlordimeform in 1966 and cartap in 1967. Parathion production was stopped because of human toxicity in 1969 and BHC was banned in 1971 because of environmental contamination. During the late 1960s and 1970s SB resistance buildup was limited by a decrease in pest occurrence, and most farmers considered pest control unnecessary.

Since 1978, however, SB incidence has increased in several areas in southern Japan, and most new populations have high-level resistance to organophosphates (Table 2), which may have developed as a side effect of insecticides applied to control leafhoppers, planthoppers, and leaffolder *Cnaphalocrocis medinalis.* SB incidence is expanding.

Small brown planthopper (SBPH) *Laodelphax striatellus*

SBPH transmits rice striped virus and black-striped dwarf and occurs throughout Japan, even in snowy areas. They hibernate as 4th-instar nymphs in diapause. Sporadic severe occurrence was observed in the 1960s, when aerial application of malathion was the predominant control.

SBPH malathion resistance appeared in 1964, as did BHC resistance. Malathion and BHC were replaced by fenthion, fenitrothion, disulfoton, and carbamates.

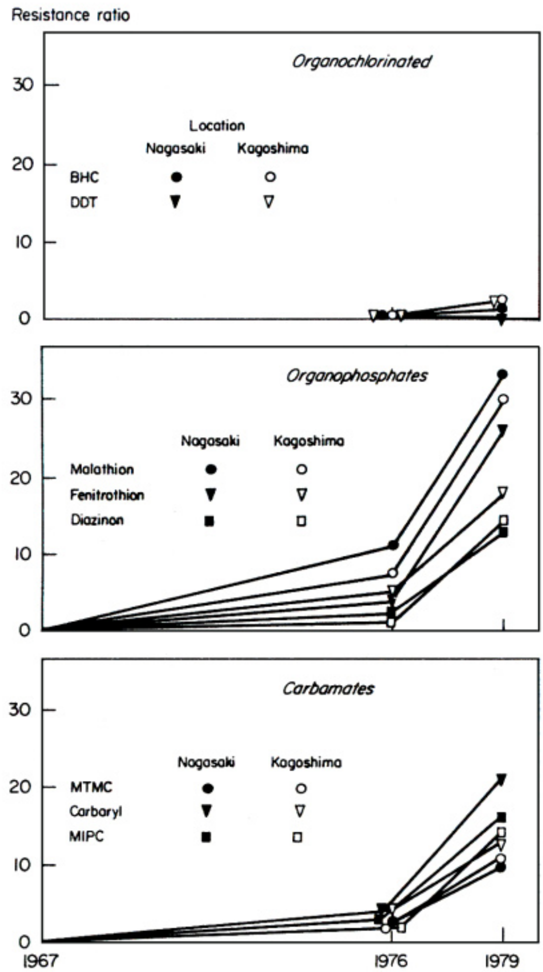
Large decreases in area planted to wheat, an alternate SBPH host, took place after 1969. Pest incidence was substantially reduced and the diseases it transmits are no longer of economic importance. However, since 1974, when the Japanese Government began to enlarge the area planted to wheat, SBPH has increased substantially in central and northern Japan.

Comparative data on 1967 topical applications show that SBPH is developing resistance to organophosphates (malathion, fenitrothion, and diazinon). A 1976 survey shows a 10– to 20-fold increase of LD_{50} and slightly increased carbamate resistance (Fig. 2). Data from several populations collected at Kyusyu in 1980 showed further increases in organophosphate resistance: 92- to 287-fold in malathion, 31 -to 46-fold in fenitrothion, and 30- to 40-fold in diazinon. Carbamate

Table 2. Development of organophosphate resistance in the striped stem borer *C. suppressalis* in Japan.

Insecticide	1960[a] Kagawa prefecture	LD_{50} (µg/g) in 1981[b] Tokusima prefecture (2-5)[c]	Okayama prefecture (6-7)[d]
Diazinon	3.59	12.3-21.0	8.9-79.2
Fenitrothion	2.16	45.3-58.1	4.7-99.3
Fenthion	2.08	67.2-91.2	5.0-79.5
Trichlorfon	7.93	113.4-262.1	–
Cartap	–	3.4-4.1	–
Dimethylvinphos	–	1.1-1.7	0.6-1.1

[a]Ozaki et al (1971). [b]Figures in parentheses indicate the number of collecting sites compared. [c]Noguchi (1982). [d]Tanaka et al (1982).



2. Development of insecticide resistance in immigrant SBPH as expressed by resistance ratio on the basis of 1967 data in Japan (Fukuda and Nagata 1969).

resistance had increased by 9- to 21-fold in MTMC, 36- to 76-fold in carbaryl, and 23- to 26-fold in MIPC (Nagata et al 1982).

In a 1980 survey, comparative data from 7 populations collected around Kyusyu showed no significant difference in susceptibility to 8 insecticides. Levels of susceptibility were similar to those of a SBPH population collected on a ship at 31° N, 126° E 400 km from Shanghai, China, on the East China Sea. Further resistance data should be collected from sea-captured migrating SBPH populations and compared with land-captured populations.

SBPH is also an important pest in Korea, where insecticide resistance was first checked in 1973 (Choi et al 1975) and in 1974 (Song et al 1976). Rates of resistance were similar to those in Japan except for carbaryl, to which Japanese populations had developed less resistance. Substantial local differences in resistance, especially for malathion, were observed, however. Choi et al (1975) reported 8.4-fold differences among 5 locations and Song et al (1976) reported 26.1-fold differences.

Brown planthopper (BPH) ***Nilaparvata lugens***

BPH infestation in Japan once fluctuated substantially, but has stabilized to become most serious in southern Japan. Insecticides are the sole control measures because commercial resistant cultivars have not been developed.

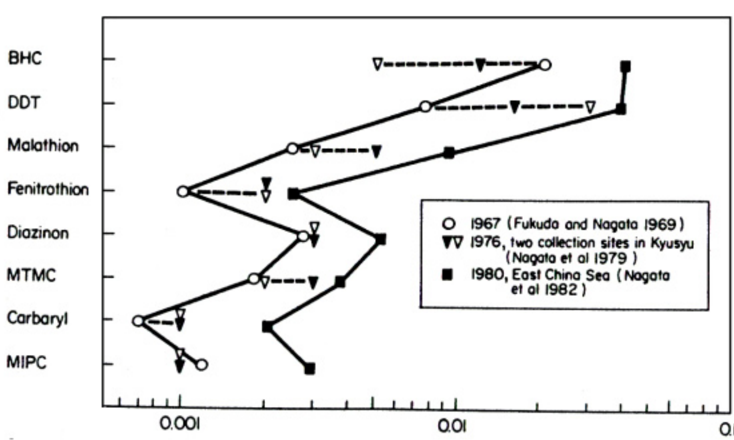
BHC and DDT were the first insecticides used to control BPH. BHC dominated because it also controlled SB, WBPH, and SBPH. Although other insects developed resistance to BHC, BPH did not show substantial resistance after 20 years (1949-71). BHC was banned and replaced with carbamates in 1971.

Studies of BHC resistance in BPH have suggested several interesting aspects of BPH insecticide resistance. Perhaps one of the reasons BPH did not develop BHC resistance is because the insect has high migrating ability. Long distance BPH and WBPH migration from outside Japan was first observed in 1967.

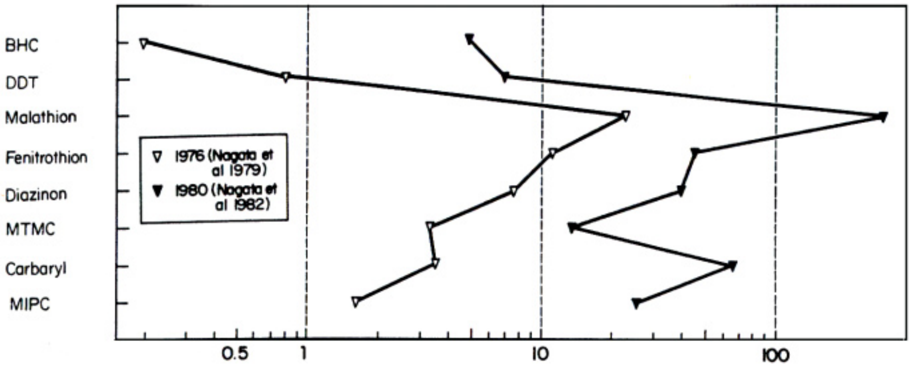
Restoration of BHC susceptibility has been observed in BPH field populations after an influx of susceptible insects. Research shows that fields treated with BHC have a zigzag-shaped resistance fluctuation. BHC-resistant populations increase rapidly with frequent insecticide applications, then die during winter. Susceptibility is restored by the migration of susceptible populations from less-treated areas during the next summer (Nagata and Moriya 1974).

BPH insecticide resistance in Japan depends primarily on the resistance level of immigrants. Immigrant BPH is developing resistance to some insecticides. Data collected at two monitoring sites on Kyusyu Island showed that LD_{50} of malathion and fenitrothion had increased significantly from 1967 to 1976. No significant increase was observed for carbamates (Nagata et al 1979, Fig. 3). By 1979 LD_{50} to organophosphates had increased further, and a 10-fold increase in carbamate resistance was recorded (Djatnika Kilin et al 1981).

That WBPH, which migrates to Japan in greater numbers than BPH, is more susceptible to insecticides shows BPH has not developed significant resistance levels. In 1980 a slight increase in LD_{50} was recorded, but it was less than 5-fold (Fig. 4).



3. Development of insecticide resistance in BPH.



4. Development of insecticide resistance in WBPH, as expressed by resistance ratio on the basis of 1967 data at Kyusyu National Agricultural Experiment Station, Japan (Fukuda and Nagata 1969).

Malathion and diazinon were recommended to control BPH until their effectiveness declined in the early 1970s. The control value of all organophosphates had declined by 1972 (Tsurumachi 1978). Carbamate effectiveness has also decreased. In 1973-74 carbamate dust gave satisfactory control in 80.7% of 60 official field tests conducted by the Japan Plant Protection Association. Control decreased to 51.6% in 93 tests in 1979-80 even though the portion of high content carbamate formulation (2%) increased from 53 to 82% (H.Yamashina, pers.comm.).

Despite gradual BPH insecticide resistance buildup, there still is a substantial stockpile of promising chemicals for BPH control, including the growth regulator buprofezin and synthetic pyrethroids. Until now new insecticide development has kept up with resistance buildup, but the situation may change in the future.

BPH insecticide resistance in Japan probably originates on the Chinese mainland, where most BPH migration to Japan originates. BPH breeds on the southern half of Hainan Island (21° N) and overwinters between 21 and 25° N, depending on annual temperature range. Northern migration begins in March and continues through August. There are five migration waves that reach 35° N, then a three-wave southern migration begins (Cheng et al 1979).

Outbreaks of BPH in China became a more serious problem during the 1970s; the increased insecticide selection pressure in that country may have developed resistance, as BPH-resistant rice varieties are not widely planted. Although a few data are available on BPH migration from tropical regions to China, some toxicological data available from Thailand (Nagata and Masuda 1979), the Philippines (IRRI 1979, Nagata and Masuda 1979), and Indonesia (Djatnika Kilin et al 1979) indicate BPH resistance in those areas may be less than in Japan.

Hama (1982) studied homogeneity of insecticide resistance in migrating BPH populations and found that toxicological properties of insects from different migration waves varied conspicuously. Although insects were collected from the same site in southern Kyusyu in 1981, their different resistance levels may indicate that they migrated from different areas.

Characteristics of geographical BPH variation may help determine migration range and route. Nagata and Masuda (1979) showed that BPH populations collected in Thailand and the Philippines are more susceptible to some insecticides, particularly DDT, than Japanese populations. However, BPH insecticide susceptibility is not a stable sign of geographical variation.

Koike (1982) compared chromatograms of BPH protein content using an autoanalyzer, and found two different chromatograms, Philippine-type and Taiwan-type. BPH collected from eight Japanese sites had Taiwan-type chromatograms.

Insecticide resistance buildup of BPH, particularly carbamate resistance, is a matter of great importance to the Japanese pesticide industry and scientists concerned with pest control. Several researchers are conducting laboratory experiments to predict future resistance levels and develop an understanding of the cross-resistance relationship between current insecticides and candidate insecticides.

BPH resistance usually develops rapidly under laboratory selection with organophosphates (malathion, fenitrothion). Carbamate resistance develops slowly. Fifty generations of continuous BPMC selection increased topical LD_{50} only 3-5 times (A. Hosoda, pers. comm.). In Korea, Chung and Choi (1981) selected BPH for carbaryl resistance for 15 generations and observed a 2.5-fold LD_{50} increase. However, MIPC LD_{50} increased 34-fold during 16 generations of testing in Taiwan, China (Chung et al 1982). Lin et al (1979) observed 6.9-fold differences in MTMC LD_{50} in a 1979 survey of 12 Taiwan sites. Results correlated with insecticide use at the sites.

Other information on development of insecticide resistant populations is shown in Table 3, although most data are not substantiated by precise studies.

TACTICS TO PREVENT INSECTICIDE RESISTANCE

Development of insecticide resistance can be prevented by planning to prevent or delay resistance before an insecticide is released or by developing new control methods after a population has become resistant. The latter is the most practical tactic.

Resistance can be prevented by limiting the frequency and amount of insecticide application, which reduces selection pressure. However, this method is not usually practical and even uneconomical.

Ozaki et al (1973) found that rotating application of several conventional insecticides and applying a mixture of insecticides effectively prevented SBPH from developing resistance in laboratory experiments. However, recent experiments with GLH did not always limit resistance buildup (Hiramatsu et al 1976). Prevention of resistance using this technique may depend on the combination of insecticides used and genetic traits of the target insect. Further research is needed in this area.

The most popular method of controlling resistant insect populations is to use new insecticides with no cross resistance to the old pesticide. Malathion and parathion were first used for GLH control, then replaced with carbamates. Carbamates were again replaced with organophosphates such as diazinon and propaphos to which malathion- or parathion-resistant GLH showed no cross resistance. Mixed

Table 3. Rice insect pests (excluding storage pests) resistant to insecticides, in addition to those described in text.

Species	Insecticide	Region	Country	Year: First appeared	Year: Started using insecticides	References
Chilo suppressalis	parathion	Kagawa	Japan	1960	1952	Yamashina (1974)
	BHC	Kagawa	Japan	1964	1949	Yamashina (1974)
	fenitrothion		South Korea	1964	?	Choi (1965)
	fenthion		South Korea	1964	?	Choi (1965)
Laodelphax striatellus	malathion and OPs	Hiroshima, etc.	Japan	1964-65	1953	Yamashina (1974)
Leptocorisa varicornis	BHC		Sri Lanka	?	?	Wickremasinghe and Elikawela (1982)
Lissorhoptrus oryzophilus	aldrin	Texas	USA	1956	?	Bowling (1972)
	aldrin	Arkansas	USA	1963	?	Rolston et al (1965)
Nephotettix cincticeps	malathion	Koti	Japan	1961	1953	Yamashina (1974)
	malathion	Ehime	Japan	1962	1953	Yamashina (1974)
	methyl parathion	Okayama, Ehime, Kagawa	Japan	1963	1952	Yamashina (1974)
	malathion	Okayama, Sizuoka, Totigi	Japan	1964	1953	Yamashina (1974)
	carbaryl	Hukuoka, etc.	Japan	1965	1959	Yamashina (1974)
Nilaparvata lugens	EPN	Okayama	Japan	1966	1955	Tsuboi et al (1973)
	malathion	Okayama	Japan	1966	1953	Tsuboi et al (1973)
	methyl parathion	Okayama	Japan	1966	1952	Tsuboi et al (1973)
	diazinon	IRRI farm, Los Baños	Philippines	1969	?	IRRI (1970)
	carbofuran	Taiwan	China	1976	?	Ku et al (1977)
	carbofuran	IRRI farm, Los Baños	Philippines	1977	?	IRRI (1978)
	BPMC, acephate, chlorpyrifos + BPMC	IRRI farm, Los Baños	Philippines	1982	?	Mochida and Basilio (1983)
	BHC, diazinon, endrin		Sri Lanka	?	?	Wickremasinghe and Elikawela (1982)
Oulema oryzae	BHC	Hokkaido	Japan	1966	1949	Yamashina (1974)
	BHC	Sadogasima, etc.	Japan	1967-70	1949	Yamashina (1974)
Sogatella furcifera	carbaryl		Sri Lanka	?	?	Wickremasinghe and Elikawela (1982)

formulations of organophosphates and carbamates also have been used to overcome carbamate resistance (Hama and Iwata 1973, Yoshioka et al 1975).

All of these insecticides are gradually losing effect because GLH is developing multiple resistance. Few promising chemicals are now available to destroy resistant GLH populations except some pyrethroids.

Laboratory use of synergists that inhibit specific detoxification enzymes in resistant insects has been documented but is not yet a practical resistance control technology. Negatively correlated resistance between propaphos and propoxur was observed for GLH (Iwata and Hama 1981). Kassai and Ozaki (1978) showed that laboratory-developed malathion resistance of BPH and SBPH was negatively correlated with resistance to fenvalerate. These facts should be considered in developing effective countermeasures to resistance buildup.

CONCLUSION

When general economic and climatic conditions in Asian rice growing countries are evaluated, varietal resistance is probably the most desirable method of controlling rice insect pests. If varietal resistance is the only measure, however, there is always the danger that new insect biotypes will develop and destroy large crop areas. Insecticide use will continue to increase gradually, even in areas where insect-resistant varieties are planted and integrated pest management techniques are used.

Japan, as an early user of extensive insecticide control measures, has been troubled by the buildup of insecticide resistance, which should be a warning to countries that are trying to expand insecticide use. Reckless choice or supply of insecticides for economic or political reasons often encourages resistance buildup. We must always hold ourselves ready to answer the question "How can we use an insecticide effectively and safely for the longest period?"

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DISCUSSION

MAGALLONA: Is insecticide resistance really inevitable even if pesticide use is managed as suggested, e.g. use in IPM/IPC, spot treatments, etc. In other words, do we know enough to prevent resistance from developing?

NAGATA: Theoretically. we can delay resistance development by careful insecticide use as suggested in the IPM concept. However, resistance will eventually develop as long as we use insecticides. In a sense, it is also a socioeconomic problem. Most of the methods suggested for preventing resistance development are labor consuming. For example, spot treatments. are economically practical only when labor is cheap.

SADJI: One of the tactics for preventing insecticide resistance is rotating applications of several conventional insecticides. How would you practice that in the field?

NAGATA: This recommendation is not very useful because the supply of insecticides by pesticide industries and choice of insecticides by farmers are done for diverse, mainly economic reasons. Farmers are reluctant to bother with future problems when they still have good control of impeding pests. Therefore, the supply of insecticides must be planned by some centralized agency according to the rotational-use schedule.

HEINRICHS: You indicated that there is an increase in the level of insecticide resistance in the BPH migrating from the tropics, possibly Southern China. Do Japanese scientists have any linkage with China to enable them to study the insecticides China is using and is the Japanese BPH resistant to those insecticides?

NAGATA: We concluded a cooperation treaty on agricultural technology last year and sent missions to China to conduct research on natural enemies of citrus, insect migration, and the pesticide industry. BHC and methyl parathion are mainly used against BPH in China. Direct corresponding relations can not always be expected between the kinds of insecticides used there and the resistance development in the immigrant BPH observed in Japan because cross resistance disturbs such correspondence.

KENMORE: Have the mixtures of malathion and propoxur developed in Japan over 10 years ago to retard the development of insecticide resistance in the green leafhopper been successful?

NAGATA: Yes, resistance has developed only gradually.

BATEMAN: We hear conflicting reports on the relationship between the use of mixtures and the development of insecticide resistance. You said that malathion and propoxur retard the development of resistance, and others say that mixtures should be avoided. For example, IRRI has recommended the mixture of chlorpyrifos and BPMC (Brodan).

NAGATA: As a general principle, mixtures should be avoided as they lead to a more rapid development of resistance in a population. However, once a pest such as the green leafhopper has become resistant to most insecticide groups, mixtures can be attempted as a last resort.

HEINRICHS (comment): IRRI, as an international organization is in no position to make recommendations to farmers.

HEINRICHS: Because you have detected the development of higher levels of insecticide resistance in BPH over the years, and given that this pest does not overwinter in Japan but migrates each year from China, have you attempted to gather information on insecticide usage from China?

MOCHIDA: Yes, research institutes of the Ministry of Agriculture are involved in this now.

KENMORE: Do insect populations become resistant to synergistic combinations more quickly than they become resistant to single compounds?

NAGATA: It depends on the kind of insecticides to be combined, pest species, and genetic composition of insect population. Some reports indicate that specified mixtures of insecticides delayed resistance development in *L. striatellus,* but recent experiments on *N. cincticeps* did not always give such favorable results. So, general conclusions can not be drawn.

MOCHIDA: In tropical rice-growing countries, we are considering the acceptance of mixture formulations and tank mixtures. Are mixtures always dangerous in developing insecticide resistance?

NAGATA: Some combinations give favorable results, delaying development of resistance, as shown in laboratory experiments on *L. striatellus* conducted in Japan. However, some workers have observed adverse results. Therefore, general conclusions can not be drawn at present. We have to check the combinations of pesticides and the genetic components of target pest populations through preliminary experiments.

FACTORS CONTRIBUTING TO BROWN PLANTHOPPER RESURGENCE

S. Chelliah and E. A. Heinrichs

There have been significant advances in noninsecticidal pest management. Insecticides, however, are still indispensable to rice farmers because they are effective, easy to use, and provide immediate results.

Synthetic organic insecticides provide effective insect control, but their widespread use has resulted in toxicity to natural pest enemies, toxic residues in plants and the environment, and insect resistance. Resurgence of some pests after insecticide application on rice is becoming common. Such an abnormal increase in the pest population after insecticide application often far exceeds the economic injury level.

Insecticide-induced pest outbreaks have been reported in walnut (Barlett and Ewart 1951), hemlock (McClure 1977), soybeans (Shepard et al 1977), and cotton (Bottrell and Rummel 1978).

Among the pests infesting rice, the brown planthopper (BPH) *Nilaparvata lugens* (Stål) has gained major importance in several Asian countries. Introduction of high yielding, BPH-susceptible rice varieties, use of high levels of nitrogen fertilizers, continuous cropping, staggered planting, and use of some insecticides are the reported causes for increased BPH populations. Throughout Asia, insecticide is an important component of BPH control, especially in countries where commercial, resistant varieties are not available.

Continuous use of insecticides has resulted in BPH resistance to insecticides in Taiwan (Lin et al 1979), Japan (Nagata 1979), and the Philippines (Heinrichs 1979). After application of insecticides, BPH resurgence was reported in Bangladesh (Alam and Karim 1977), India (Varadharajan et al 1977, Chandy 1979), Indonesia (Oka 1978, Soekarna 1979), the Philippines (IRRI 1979), and the Solomon lslands (Stapley et al 1979). Most of the hopperburned fields reported or observed in India, Indonesia, Philippines, and Sri Lanka received insecticides before the outbreak.

Detailed investigations have been made in the past few years on the insecticide-induced BPH resurgence in rice (Chelliah 1979; Chelliah and Heinrichs 1980; Chelliah et al 1980; Raman 1981; Heinrichs et al 1982a, b; Reissig et al 1982a, b).

FACTORS CONTRIBUTING TO RESURGENCE

Research indicates that a variety of factors contribute to BPH resurgence. The

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degree of resurgence is dependent on the method, timing, and number of insecticide applications and the level of varietal resistance to BPH.

Suppression of natural enemies

Suppression of natural enemies following intensive broad-spectrum insecticide application was suggested as an important factor for BPH resurgence in rice (Kiritani 1972, 1975; Kiritani et al 1971; Kobayashi 1961; Miyashita 1963). Dyckand Orlido (1977) reported that reduction in the population of the mind predator *Cyrtorhinus lividipennis* after regular spraying with methyl parathion caused BPH resurgence. However, extensive field studies conducted later did not show adequate evidence that reduction in the *C. lividipennis* population caused the resurgence (IRRI 1978, Chelliah 1979).

Reissig et al (1982b) indicated that when BPH resurgence occurred in the field, the population of the most important predators such as spiders *C. lividipennis* and *Microvelia atrolineata* could not increase to a sufficient level to suppress the increasing BPH population. Their investigations further indicated that when resurgence-inducing insecticides were applied in the field, they stimulated BPH population growth regardless of their relative toxicity to natural enemies. Natural enemy destruction was a minor factor (Chelliah 1979, Heinrichs et al 1982).

Insecticide-induced plant growth

Heinrichs et al (1979) reported that, in rice, paddy water application of granular formulations of carbofuran, isazophos, ethoprop, and acephate significantly increases plant height. Spraying rice plants with methyl parathion induced tillering (Chelliah 1979). Recently, Raman (1981) reported that foliar application of deltamethrin and methyl parathion resulted in increased number of tillers and leaves and increased plant height. The phytotonic effect (healthy, green plants) of certain insecticides may attract more macropterous hoppers immigrating into rice fields. The alighting followed by increased feeding, reproduction, and longevity would increase BPH resurgence.

Feeding rate

The feeding rate of the BPH was observed to be significantly increased at sublethal doses of resurgence-inducing insecticides. Chelliah and Heinrichs (1980) observed that, in rice plants sprayed with three resurgence-inducing insecticides *viz* deltamethrin, methyl parathion, and diazinon, the BPH feeding rate was higher than that of the check by 61, 43, and 33% respectively. They further reported that, although the first two insecticides induced plant growth, the improved growth did not compensate for the higher rate of BPH feeding leading to hopperburn of these plants much earlier. Subsequent studies by Raman (1981) showed that other resurgence-inducing insecticides such as quinalphos, cypermethrin, fenthion, permethrin, and fenvalerate also increased the BPH feeding rate.

Influence on BPH biology

Chelliah (1979) and Heinrichs et al (1982) demonstrated that BPH population increase after insecticide application was due to stimulation of hopper reproduction.

In laboratory studies, Raman (1981) observed that the BPH reproductive rate was enhanced when the hopper was feeding on rice plants sprayed with deltamethrin, methyl parathion, quinalphos, cypermethrin, permethrin, and fenvalerate. The increased reproduction might be due to the action of insecticide residues or their metabolites, chemical changes in the host plant receiving insecticides, or a combination of these factors. Reduction in the length of the nymphal stage resulting in a shortened life cycle and increased adult longevity resulting in a longer oviposition period were additional factors contributing to resurgence (Chelliah 1979).

Changes in the nutrient content of the rice plant

Mani and Jayaraj (1976) reported that a low concentration of calcium and high levels of nitrogen and phosphorus in insecticide-applied plants contributed to resurgence of the blue leafhopper *Zygina maculifrons* (Motch). However, in chemical analyses of major and minor nutrients in rice plants protected with insecticides, Chelliah and Heinrichs (1978) did not find any marked BPH resurgence. This area needs further investigation because other nutrients in the plants might provide nutritional evidence on BPH resurgence.

Effect of sublethal doses

To save money, farmers are using low insecticide doses. This practice, combined with the short residual toxicity of many commercial insecticides, will often cause the BPH to be exposed to sublethal insecticide doses. Chelliah (1979) reported that low doses of resurgence-inducing insecticides increased the reproductive rate of the BPH and reduced the nymphal duration, eventually leading to resurgence.

Insecticide classes and resurgence

Insecticides causing resurgence include some synthetic pyrethroids, organophosphates, and carbamates. No single class of insecticide has been identified to be free from resurgence-inducement (Chelliah 1979, Reissig et al 1982b).

Insecticide rates

Insecticide rates had distinct influence on the degree of BPH resurgence. Heinrichs et al (in press) observed that deltamethrin at 30 g ai/ha induced significantly high BPH population compared with 20 and 10 g ai/ ha. With methyl parathion, resurgence rate was highest at 750 g ai/ ha compared with 500 and 250 g ai/ha (Table 1).

Timing and number of application

The timing and number of insecticide applications ultimately govern BPH resurgence. Foliar sprays applied at 50 and 65 DT (days after transplanting) resulted in a high BPH egg and subsequent nymphal population, reaching a peak at 80 DT (Heinrichs et al 1982).

Method of insecticide application

Heinrichs et al (1982) found that foliar spraying induced more BPH resurgence than root zone placement and broadcasting (Table 2).

Table 1. ***N. lugens*** **population in field plots of rice variety IR22 treated with 3 rates of deltamethrin and methyl parathion as foliar sprays (Heinrichs et al, in press).**

Insecticide[a]	Rate (kg ai/ha)	*N. lugens*/hill[b] (no.)
Deltamethrin	0.03	850 a
	0.02	220 bc
	0.01	210 bcd
Methyl parathion	0.75	360 b
	0.50	145 cd
	0.25	112 cd
Check	–	60 d

[a] Insecticides were applied with a knapsack sprayer at 20, 35, and 50 days after transplanting (DT). [b] Sample means of *N. lugens,* taken at 68 DT, followed by a common letter are not significantly different at the 5% level.

Influence of insecticide on nymphal and adult stages

The reproductive rates of BPH exposed to insecticide-sprayed plants during nymphal or adult stage or both varied significantly (Chelliah 1979). The reproductive rate was significantly higher when the BPH was exposed to plants sprayed with resurgence-inducing insecticides at the fourth- and fifth-instar stage as well as at the adult stage (Table 3).

Genetic resistance of rice varieties

In BPH management, resistant rice varieties, planted over large areas in Asia, play an important role. Reissig et al (1982a) demonstrated through a field experiment that the extent of BPH resurgence after insecticide application decreased as varietal

Table 2. Influence of method of carbofuran application on BPH population and degree of hopperburn[a] (Heinrichs et al 1982).

Application method	BPH (no./hill)	Hopperburned hills (%)
	Experiment 1[b]	
Root zone	87 b	14 b
Broadcast	44 b	4 b
Foliar spray	149 a	97 a
Check	120 b	8 b
	Experiment 2[c]	
Root zone	1196 ab	19 a
Broadcast	541 bc	16 a
Foliar spray	2456 a	25 a
Check	123 d	18 a

[a] In a column, means followed by a common letter are not significantly different at the 5% level. [b] Root zone application made 5 days after transplanting (DT) at 1.0 kg ai/ha; broadcast application at 1.0 kg ai/ha and foliar sprays at 0.5 kg ai/ha, both at 5, 25, 45, and 72 DT. BPH population and hopperburn were recorded at 78 and 92 DT, respectively. [c] All applications made at 0.75 kg ai/ha 25, 45, and 72 DT. BPH population and hopperburn were recorded at 71 and 84 DT, respectively.

Table 3. Resurgence of BPH as influenced by exposure of different nymphal stages and adult to insecticide-sprayed rice plants.

Stage at exposure[a]	Nymphs hatched[b] (no.)				
	Methyl parathion	Deltamethrin	Diazinon	Perthane	Check (water spray)
First instar to adult	336.7 c	363.3 d	291.7 a	140.3 b	225.3 a
Second instar to adult	375.3 c	386.0 cd	297.0 a	169.0 ab	225.0 a
Third instar to adult	422.3 b	407.3 bc	309.7 a	178.3 ab	262.0 a
Fourth instar to adult	438.0 ab	448.3 ab	334.3 a	192.7 a	241.7 a
Fifth instar to adult	450.3 ab	461.7 a	316.7 a	188.3 a	236.3 a
Adult	472.7 a	484.3 a	315.3 a	188.7 a	252.7 a

[a]Insecticide sprayed on plants aged 20, 30, and 40 days. Insects were released on plants 10 days after third spraying. [b]From eggs laid by 2 females in 7 days. In a column, means followed by a common letter are not significantly different at 5% level.

resistance increased. Populations in insecticide-treated plots compared with untreated plots were 74- 50- and 5-fold for susceptible, moderately resistant, and resistant varieties, respectively. Resurgence-causing insecticides should not be used indiscriminately on moderately resistant varieties because they contribute to a BPH population increase above economic injury levels and accelerate the biotype selection process.

CONCLUSION

Investigations have indicated that many factors are involved in inducing BPH resurgence. Some insecticides contribute to a favorable environment in the rice ecosystem for the BPH to alight, feed, and survive. This stimulates BPH reproduction leading to a high population buildup and severe damage.

Rice production in Asia is being limited by insecticide-induced BPH outbreaks. To prevent outbreaks, a more natural pesticide management program must be adopted. National programs must thoroughly evaluate candidate insecticides to identify those causing BPH resurgence.

Although identifying insecticides that induce resurgence is important in an insecticide evaluation program, their use for increasing field population of rice insects in varietal screening is also valuable.

Brown planthopper

When screening to identify BPH-resistant rice varieties, the pest's unpredictability can cause high expenditures without desired results. Researchers are using resurgence-inducing insecticides to maintain BPH populations for varietal screening work. Insecticides that work well for this purpose include the synthetic pyrethroids deltamethrin and cypermethrin and organophosphates such as methyl parathion, diazinon, azinphos ethyl, and quinalphos (Heinrichs et al 1978).

Leaffolder

Optimum field populations of the leaffolder *Cnaphalocrocis medinalis* are also essential for objective varietal screening. Phorate 10G application along with adoption of closer plant spacing and a higher dose of nitrogen fertilizer promoted plant growth and heavy leaffolder infestation (Velusamy and Chelliah, unpubl.). The leaffolder population was built up on susceptible plants located around the experimental field. The moths later moved to the test entries, providing a high level of infestation.

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DISCUSSION

RENDELL: Have any studies been made on the surface structure of the rice plant in relation to resurgence in inducing insecticides? I noticed from the pattern of BPH honeydew spots on filter paper that with resurgence-causing insecticides the insects stayed stationary, but in nonresurgence-causing insecticides the insects moved around.

CHELLIAH: No studies on the surface morphology of the rice plant have been made in this area. In this study however, hoppers, whether on resurgence or nonresurgence-inducing insecticide-treated plants, were highly sedentary.

SAXENA: Have you considered that BPH resurgence may be induced by insecticidal effects on pathogens?

CHELLIAH: No studies have been carried out.

LOWE: Has resurgence been found with pests other than BPH and leaffolder?

CHELLIAH: The whitebacked planthopper populations exhibit resurgence from methyl parathion, diazinon, and deltamethrin.

BATEMAN: Has leaffolder resurgence been caused by insecticides other than phorate G?

CHELLIAH: Yes, by carbofuran G.

LIM: Road dust is known to stimulate spider mite populations. Have you studied dust formulations for their potential to stimulate resurgence?

CHELLIAH: No, we have tested only granule and emulsifiable concentrate formulations, because they are most commonly used in the areas where resurgence has been reported.

DANDI (comment): In Indonesia, we also have found that BPH resurgence does not appear to be related to depressed natural enemy numbers nor to resistant varieties. We still do not know the cause of resurgence. However, laboratory experiments have shown that sublethal doses of insecticides cause resurgence of the armyworm *Spodoptera litura.*

SANCHEZ(comment): The mango hopper in the Philippines undergoes population explosions during the mango blossoming period, supporting the observation that improved nutrition may cause resurgence.

CHELLIAH (comment): Yes, the mango hopper is known to breed only during the mango blossoming period.

PERFECT (comment): We must be cautious about our interpretations leading to conclusions that resurgence in BPH is not related to natural enemy numbers and does not occur on resistant varieties. Field trials carried out in small plots may give biased results because natural enemies can quickly reinvade from neighboring plots. Predator-prey ratios, rather than actual numbers, are better indicators of natural enemy effect because many natural enemies are density dependent.

Evidence also shows that BPH numbers increase up to fivefold on resistant varieties. This increase does not lead to hopperburn but has serious implications for the development of biotypes that can attack resistant varieties. Therefore, resurgence-causing insecticides jeopardize resistant varieties.

LITSINGER: A number of people have failed to demonstrate resurgence in their countries. What is your recipe for inducing resurgence in BPH?

CHELLIAH: To induce resurgence, there must be a population to begin with. One can set out lights to attract hoppers, use high levels of nitrogen fertilizer, and time fertilizer application when the hoppers are adults.

ISHIKURA: In parts of Japan, farmers use two insecticide applications on rice for stem borer, one in midsummer, when temperatures are high, and the second in the fall, when temperatures are cool. BPH resurgence in Japan has been noted after the midsummer application during hot weather but not during cool periods. Temperature therefore may be important.

CHELLIAH: (comment) In the tropics, where resurgence has been reported, temperatures are always high and relatively constant. Therefore, we have not considered this factor.

TESTING THE SIDE EFFECTS OF PESTICIDES ON BENEFICIAL ARTHROPODS

S. A. Hassan

Testing the side effects of pesticides on beneficial arthropods is gaining more attention in a number of countries; standard test methods are therefore needed now.

The Working Group "Pesticides and Beneficial Arthropods" of the International Organization for Biological Control attempts to design a procedure for testing the side effects of pesticides on beneficial arthropods, using laboratory, semifield, and field test methods. To initiate further discussions, the present state of the procedure is summarized.

One of the main objectives of the Working Group *Pesticides and Beneficial Arthropods* of the International Organization for Biological Control (IOBC), West Palearctic Regional Section (WPRS), is to organize joint pesticide-testing programs and to provide needed information on the side effects of pesticides on beneficial arthropods. Results of testing 40 pesticides on 12 beneficial arthropods in 6 countries have been published in two multi-author publications (Franz et al 1980. Hassan et al 1983, Table 1, 2). Methods that have common characteristics and a common evaluation technique were developed so that results can be compared.

There is general agreement that pesticides should first be tested on several arthropods in the laboratory, and that these arthropods should be related to the crops on which the pesticide is to be used. The number of beneficial species to be tested with each pesticide ought to differ according to the crops for which the pesticide is to be used. A total of 4 to 6 beneficial species for each pesticide has been suggested by the group members.

Arthropods appropriate for the test could be selected with the aid of the following key:

- Crops with aphids as pests: at least 1 aphd predator (i.e. Chrysopidae, Coccinellidae, Syrphidae) and at least 1 aphid parasite (i.e. Aphidiinae).
- Crops with Lepidoptera as pests: at least 1 egg parasite (i.e. Trichogrammatidae) and 1 larval (pupal) parasite (i.e. Tachinidae, Braconidae, Ichneumonidae).
- Crops with mites as pests: at least 1 predator (i.e. *Typhodromus* sp., *Amblysesius* sp., and/or Anthocoridae, for glasshouse crops *Phytoseiulus* sp.).
- Crops with psylla as pests: Anthocoridae.
- Crops with flies as pests: at least 1 parasite (i.e. Cynipidae, Ichneumonidae).

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Table 1. Results of the second joint pesticide testing program of the Working Group "Pesticides and Beneficial Arthropods" (S. A. Hassan et al 1983).

Preparation (active ingredient)	Concn tested (%)	Initial toxicity[a]									Persistence[b] of *Trichogramma*
		A	B	C	D	E	F	G	H	I	
Insecticides, acaricides											
Dipel (*Bacillus thuringiensis*)	0.10	1	1	1	1	1	1	1	2	1	
Torque (fenbutatin-oxide)	0.05	1	1	1	1	1	1	1	2	1	
Dimilin (diflubenzuron)	0.05	1	1	1	1	1	4	1	1	1	
Kelthane Hoechst (dicofol)	0.15	3	3	2	4	1	1	3	4	4	2
Spruzit-Nova-flüssig (pyrethrum + pip. but.)	0.10	4	3	1	3	1	1	4	4		2
Plictran 25 W (cyhexatin)	0.10	4	2	1	1	2	4	4	3	4	4
Pirimor-Granulat (pirimicarb)	0.10	4	4	4	2	1	1	4	3	3	1
Metasystox (i) (demeton-S-methyl)	0.10	4	3	4	4	2	4	4	4	4	3
Thiodan 35 Spritzp. (endosulfan)	0.10	4	4	4	2	4	1	4	4	2	3
Rubitox-Spritzpulver (phosalone)	0.20	4	4	4	4	4	1	4	3	4	4
Fungicides											
Nimrod (bupirimate)	0.04	1	1	1	1	1	1	1	1	1	
Cercobin-M (thiophanate-methyl)	0.10	1	1	1	1	1	1	1	2	4	
Ortho Difolatan (captafol)	0.20	1	1	2	1	1	1	1	3	1	
Dithane Ultra (mancozeb)	0.20	3	1	1	1	1	3	3	3	3	
Euparen (dichlofluanid)	0.20	4	2	2	2	1	2	3	2	2	3
Afugan WP 30 (pyrazophos)	0.05	4	4	4	1	4	3	4	4	4	4
Herbicides											
Betanal (phenmedipham)	2.25	1	1	1	1	1	2	2	4	4	
Illoxan (diclofop methyl)	0.75	2	1	1	2	1	1	1	2		
Kerb 50 W (propyzamide)	0.75	3	1	1	2	1	1	1	3		
Aretit flüssig (dinoseb)	1.25	4	4	4	4	4	4	4	4	4	

[a]Initial toxicity: 1 = harmless (<50%), 2 = slightly harmful (50-79%), 3 = moderately harmful (80-99%), 4 = harmful (>99%). A = *Trichogramma,* B = *Pales,* C = *Phygadeuon,* D = *Leptomastix,* E = *Coccygomimus,* F = *Chrysopa,* G = *Encarsia.* H = *Syrphus,* I = *Amblyseius.* [b]Persistence: 1 = short-lived (<5 days), 2 = slightly persistent (5-15 days), 3 = moderately persistent (16-30 days), 4 = persistent (>30 days).

Table 2. Side effects of 20 pesticides on 13 beneficial arthropods. Results of the second laboratory test program undertaken in 6 countries.

Preparation (active ingredient)	Concn tested	Initial toxicity[a]													Persistence[b] of *Trichogramma*
		A	B	C	D	E	F	G	H	I	J	K	L	M	
Insecticides, acaricides															
Azomate (benzoxamate)	0.15	2	2	1	1	2	1	1	1	1	1	4			
Asepta Lindane (lindane)	0.10	4	4	4	3	3	4	1	2	1	1	4			2
Dipterex WP 80 (trichlorfon)	0.10	4	4	4	3	3	4	4	4	4	1	4		1	3
Peropal (azocyclotin)	0.10	4	3	3	4	3	4	3	4	1	3	3			3
Lannate (methomyl)	0.10	4	4	4	4	4	4	4	4	3	3	4	4		4
Unden (propoxur)	0.15	4	3	4	4	3	4	4	4	3	4	4	4		2
Sumicidin (fenvalerate)	0.075	4	4	4	4	4	4	1	4	4	3	4	4		4
Actellic 50 (pirimiphos-methyl)	0.2	4	3	4	4	4	4	4	4	4	4	4		1	4
Ultracid (methidathion)	0.075	4	4	4	4	4	4	4	4	4	4	4	4		4
Ambush (permethrin)	0.02	4	4	4	4	3	4	4	4	4	4	4	4	4	4
Fungicides															
Orthocid 83 (captan)	0.15	1	1	1	1	1	1	1	1	1	1	3	1	1	
Bayleton (triadimefon)	0.10	1	1	1	1	1	1	1	1	1	1	2	1		
Ronilan (vinclozolin)	0.05	1	1	1	1	1	1	1	1	1	1	1			
Derosal (carbendazim)	0.05	1	1	1	1	1	1	1	4	3	1	1		1	
Plondrel (ditalimfos)	0.075	3	3	3		1	2	1	2	1	1	1		1	3
Thiovit (sulfur)	0.40	4	2	4	1	1	1	2	3	1	1	2	1		4
Herbicides															
Semeron (desmetryn)	0.25	4	1	1	1	1	1	1	1	2	1	1			2
Average (difenzoquat)	1.00	4	3	4	4	3	1	1	4	4	1	3			2
Ramrod (propachlor)	1.00	4	3	4	4	3	4	1	3	3	1	3			2
Aresin (monolinuron)	0.75	4	4	4	4	3	4	1	4	3	2	3			

[a] Initial toxicity: 1 = (<50%), 2 = slightly harmful (50-79%), 3 = moderately harmful (80-99%), 4 = harmful (>99%). A = *Trichogramma,* B = *Drino,* C = *Encarsia,* D = *Leptomastix,* E = *Opius,* F = *Phygadeuon,* G = *Coccygomimus,* H = *Amblyseius,* I = *Phytoseiulus,* J = *Chrysopa,* K = *Syrphus,* L = *Anthocoris,* and M = *Cryptolaemus,* [b] Pesistence: 1 = short-lived (<5 days), 2 = slightly persistent (5-15 days), 3 = moderately persistent (16-30 days), 4 = persistent (>30 days). A = *Trichogramma.*

- When soil is treated: at least 1 predator (i.e. Carabidae, Staphylinidae) and 1 soil-living parasite (i.e. Cynipidae, Ichneumonidae).
- Glasshouse crops with whiteflies as pests: the parasite *Encarsia formosa.*

Pesticides found to be harmless to a particular beneficial arthropod in the laboratory are most likely to be harmless to the same organism in the field; no further testing in semifield or field experiments is recommended. Exceptions to this rule are few. Further testing is recommended when a pesticide is found to harm the arthropod in the initial toxicity test. This further testing should include a test to determine the duration of the harmful activity, a semifield test to find out the effect of a dry pesticide film on plant or soil, or a field test to show the effect of a direct spray of pesticide on plants or soil inhabited by beneficial arthropods.

LABORATORY INITIAL TOXICITY TEST

Beneficial arthropods of the same age are exposed to a fresh, dry, pesticide film applied at recommended concentrations on glass plates, plant leaves, or soil depending on the behavior of the arthropods. The tests are carried out under temperature and humidity conditions favorable to the arthropod. Mortality in water-treated control units should not exceed specified limits. Forced ventilation to prevent the accumulation of pesticide fumes is provided. Reduced arthropod capacity or mortality is then measured.

Information on the test methods for the following beneficial arthropods has been published: *Trichogramma cacoeciae* initial toxicity (Hassan 1974, 1977), persistence (Hassan 1980, 1983, Table 3); *Coccygomimus turionellae* (Bogenschotz 1975); *Phygadeuon trichops* (Plattner and Naton 1975, Plattner 1979); *Chrysopa carnea* (Suter 1978); *Leptomastix dactylopii* (Viggiani and Tranfaglia 1978); *Pales pavida* (Huang 1981); *Amblyseius potentillae* (Overmeer and Van Zon 1982); *Phytoseiulus persimilis* (Samsøe-Peterson 1982).

PERSISTENCE

Persistence (the duration of harmful activity) is tested by the following methods: plants or soil are wet sprayed and kept either in a field-simulated environment or in the field but under a transparent polyethylene rain cover. Beneficial arthropods are then exposed to samples of the treated substratum taken at different time intervals up to 30 days after pesticide application. When interpreting the results of these tests, it should be borne in mind that rain was excluded. Methods to test the persistence of pesticides for *T. cacoeciae, L. dactylopii, C. turionellae, D. inconspicua,* and *E. formosa* are established and several more are in progress.

SEMIFIELD TESTS

Laboratory-reared arthropods are exposed to a fresh dry pesticide film applied on plants or soil and placed in field cages. The cages are placed in the field under rain cover and partial shade. Semifield methods are being developed for *T. cacoeciae, C. carnea, C. turionellae, D. inconspicua, P. trichops, A. potentillae, E. formosa, P. persimilis* and several more are planned.

Table 3. Effects of pesticides on *Trichogramma cacoeciae.*

Active ingredient	Content	Trade name	Concn (%)	Initial toxicity[a]		Persistence[b]	
				Beneficial capacity (%)	Category	In days	Category
Fungicide							
Bupirimat	250 g/l	Nimrod	0.04	0	1		
Triforin	190 g/l	Saprol	0.15	0	1		
Captan	83 %	Orthocid 83	0.15	0	1		
Captafol	80 %	Ortho Difolatan	0.20	2.5	1		
Captan	50 %	Orthocid 50	0.20	6.6	1		
Thiophanat-methyl	70 %	Cercobin M	0.10	8.1	1		
Folpet	50 %	Ortho-Phaltan 50	0.25	8.8	1		
Zineb	80 %	Fungo-Pulvit	0.20	9.0	1		
Benomyl	50 %	DuPont Benomyl	0.05	10.1	1		
Metiram	80 %	Polygram Combi	0.20	11.0	1		
Kupferoxychlorid	45 %	Funguran	0.50	12.9	1		
Carbendazim	59.4 %	Derosal	0.05	14.0	1		
Triadmefon	5%	Bayleton spezial	0.10	28.3	1		
Mancozeb	80 %	Dithane Ultra	0.20	84.8	3		
Vinclozolin	50 %	Ronilan	0.10	84.9	3		
Thiram	80 %	Pomarsol forte	0.20	85.2	3	>31	4
Dodemorph-acetat	400 g/l	BASF Mehltaumittel	0.25	89.9	3		
Propineb	70 %	Antracol	0.25	90.1	3	>31	4
Dinocap	19 %	Karathane	0.10	94.6	3	8	2
Ditalimfos	50 %	Frutogard	0.08	96.9	3	19	3
Dichlorfluarid	50 %	Euparen	0.20	97.5	3	22	3
Triadimefon	100 g/l	Bayleton 100	0.20	97.8	3		
Ditalimfos	50 %	Plondrel 50 W (B)	0.075	91.9	3	21	3
Chinomethionat	25 %	Morestan-Spritzp.	0.05	100	4	6	2
Schwefel	80 %	Sufran	0.25	100	4	8	2
Pyrazophos	293 g/l	Afugan	0.05	100	4	>31	4
Pyrazophos	30 %	Afugan 30 WP	0.05	100	4		
Dinobuton	48.5 %	Wacker Acrex	0.10	100	4	>31	4

Continued on next page

Table 3 continued

Active ingredient	Content	Trade name	Concn (%)	Initial toxicity [a]		Persistence [b]	
				Beneficial capacity (%)	Category	In days	Category
Herbicide							
Lenazil	80 %	Venzar	1.00	0	1		
Diuron + Bromacil	8 + 32%	RA 17 - Neu	1.00	22.1	1		
Phenmedipham	157 g/l	Betanal	2.25	28.7	1		
Simazin	50 %	Gesatop 50	0.50	37.0	1		
Chloridazon	65 %	Pyramin	2.00	44.2	1		
Diclofop-methyl	360 g/l	Dioxan	0.75	78.3	2		
Desmetryn	25 %	Semeron 25	0.75	86.7	3		
Propyzamid	48.5 %	Kerb 50 W	0.75	95.2	3		
Propachlor	65 %	Ramrod	1.00	100	4	7	2
Difenzoquat	200 g/1	Avenge	1.00	100	4	14	2
Monolinuron	47.5 %	Aresin	0.75	100	4		
Alachlor	480 g/l	Lasso	3.50	100	4		
Dinoseb-acetat	492 g/1	Aretit flussig	1.25	100	4		
Insecticide							
Bacillus thuringiensis	3.2 %	Dipel	0.60	0	1		
Bacillus thuringiensis	3.2 %	Thuricide-HP	0.60	0	1		
Diflubenzuron	25 %	Dimilin 25 WP	0.09	46.3	1		
Mevinphos	530 g/l	PD 5	0.05	100	4	< 3	1
Pirimicarb	50 %	Pirimor-Granulat zum Auflosen in Wasser	0.05	100	4	< 3	1
Pyrethrum +	4 + 16%	Rotenol-Emulsion	0.10	100	4	< 3	1
Piperonylbutoxid	4 + 16%	Spruzit-Nova-fl.	0.20	100	4	9	2
	48 g + 480 g/l	blitol Insektenfrei	0.035	100	4	12	2

Lindan	14 %	Asepta (B)	0.10	100	4	7	2
Trichlorfon	50 %	Dipterex SL	0.15	100	4	8	2
Propoxur	50 %	Unden-Spritzpulver	0.15	100	4	11	2
Chlorfenvinphos	240 g/l	Sapecron flüssig	0.10	100	4	11	2
Phosphamidon	200 g/l	Dimecron 20	0.10	100	4	15	2
Demeton-S-methyl	250 g/l	Metasystox (i)	0.10	100	4	19	3
Endosulfan	32.9 %	Thiodan 35 Spritzp.	0.10	100	4	20	3
Diazinon	235 g/l	Basudin 25 Emuls.	0.10	100	4	26	3
Diazinon	40 %	Basudin 40 Spritzp.	0.10	100	4		
Butocarboxim	500 g/l	Drawin 755	0.15	100	4		
Methomyl	25 %	Lannate 25-WP	0.10	100	4	>31	4
Pirimiphos-methyl	500 g/l	Actellic 50	0.10	100	4		
Bromophos	380 g/l	Nexion-stark	0.10	100	4	>31	4
Formetanat	50 %	Dicarzol	0.10	100	4	>31	4
Mercaptodimethur	50 %	Mesurol	0.10	100	4	>31	4
Thiocyclam	90 %	Evisect	0.075	100	4		
Phosmet	50 %	Imidan	0.10	100	4	>31	4
Phosalon	30 %	Rubitox-Spritzp.	0.20	100	4	>31	4
Dialifos	432 g/l	Torak	0.10	100	4	>31	4
Methidathion	40 %	Ultracid 40	0.075	100	4	>31	4
Permethrin	25 %	Ambush	0.02	100	4	>31	4
Fenvalerat	300 g/l	Sumicidin 30	0.075	100	4	>31	4
Acaricide							
Fenbutatin-oxid	50 %	Shell Torque	0.05	26.1	1		
Benzoximat	200 g/l	A. Azomate (B)	0.15	17.8	2	14	2
Dicofol	21.2 %	Kelthane Hoechst	0.15	96.7	3	13	2
Azocyclotin	25 %	Peropal	0.10	100	4	25	3
Cyhexatin	25 %	Plictran 25 W	0.10	100	4	>31	4
Binapacryl	48 %	Acricid conc.	0.10	100	4	>31	4

[a]Initial toxicity: 1 = (<50%), 2 = slightly harmful (50-79%), 3 = moderately harmful (80-99%), 4 = harmful (>99%). [b]Persistence: 1 = short-lived (<5 days), 2 = slightly persistent (5-15 days), 3 = moderately persistent (16-30 days), 4 = persistent (>30 days).

FIELD TESTS

Beneficial arthropods that are mass reared and released for the biological control of pests can easily be tested in the fields where released. *Trichogramma* that is used to control *Ostrinia nubilalis* can be tested in maize fields, *Encarsia formosa* that is used to control *Trialeurodes vaporariorum* and *Phytoseiulus persimilis* that is used to control *Tetranychus urticae* can be tested on glasshouse crops.

Beneficial arthropods that naturally occur in sufficient numbers on specific crops can be easily tested by spraying those crops and collecting the dead and live individuals. The number of individuals of each species or group of species has to exceed a certain limit to permit statistical analysis. Standard test methods for apple, pear, citrus, vine, cereals, and forest crops are being developed.

Although the interpretation of these three types of tests is not yet final and more data are needed, some hypotheses can be made. Pesticides that are persistent or moderately persistent and pesticides shown to be harmful or moderately harmful in semifield or field tests are bound to have more impact on the particular arthropod in nature than are short-lived, slightly persistent, harmless or slightly harmful pesticides. It is believed that harmlessness of pesticides to beneficial arthropods can be best demonstrated by laboratory tests and harmfulness by semifield and field tests or by showing the duration of their harmful activity. In comparing the procedure mentioned in this work with the normal procedure used by the pesticide industry to test the effectiveness of chemicals against pests, an obvious parallel can be drawn. Chemicals that are ineffective in the laboratory are screened out and only toxic chemicals are tested further.

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DISCUSSION

SAXENA (comment): The parameters followed for classifying toxicity of insecticides against beneficial arthropods seem to have a strong bias in favor of selecting insecticides with fairly high toxicity, e.g. 1 = harmless (50% mortality), 2 = slightly harmful (50-79%), 3 = moderately harmful (80-90% mortality), 4 = harmful (99% mortality). With such high mortality levels, chance for recovery of beneficial organisms seems remote, particularly in the case of spiders, which have long life spans and are the most important predators in agroecosystems.

HASSAN (comment): The reduction in beneficial capacity, not mortality, is evaluated. Pesticides that pass this test show no toxicity in the field. The Working Group is considering changing the classes to: 1 = harmless (30%), 2 = slightly harmful (30-79%), 3 = moderately harmful (80-99%), 4 = harmful (>99%). If this is done, for example, only 3 pesticides out of 70 will be changed from class 1 to class 2.

ISHIKURA: In your paper, you referred to literature describing the procedure of the laboratory test. Do you plan to compile a manual for detailed procedures of laboratory testing?

HASSAN: Yes, but several manuals are already available.

ISHILURA (comment): I think dust formulation should be included in your evaluation because simple dust adversely affects the activities of parasites.

HASSAN: Dust formulations should be tested, but in semifield and field tests, not in the laboratory.

ISHIKURA (comment): In the early 1940s, we investigated mass rearing of *Trichogramma* on the egg of *Ephestia* and the release of *Trichogramma* for the control of the rice stem borer, but the trial failed because the percentage of parasitism dropped quickly and it was concluded that successive releases were required for controlling such insect pests as the rice stem borer, which appear for an extended period. The investigation also indicated that *Trichogramma* wasps that emerged from *Ephestia* eggs were smaller than those that came from the stem borer eggs.

HASSAN (comment): We know much more about the mass rearing and utilization of *Trichogramma* now. Since 1977 we have been able to control the European corn borer *Ostrinia nubilalis* very successfully. In 1983 about 1,500 ha are to be treated.

LOWE: Can morecoordination, cooperation, standardization, etc., be worked out between agencies (private and otherwise)?

HASSAN: Yes, more coordination and cooperation can be worked out, as follows: a) test methods agreeable to colleagues in the different agencies can be developed, b) joint pesticide-testing programs can be organized, c) more selective pesticides can be developed more easily and cheaply for the industry. The opportunity for standardization should not be wasted.

LOWE (comment): Field evaluationof materials appears to be very feasible in Southeast Asia.

Appendix 1. Written guidelines on the test methods are also available and can be acquired from members as follows:

1. *Trichogramma cacoeciae*
   Dr. S. A. Hassan, Biologische Bundesanstalt für Land- und Forstwirtschaft, Institut für biologische Schädlingsbekämpfung, Heinrichstraβe 243, D-600 Dannstadt
2. *Coccygomimus turionellae*
   Dr. H. Bogenschütz, Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg, Abteilung Waldschutz, D-7801 Stegen-Wittental
3. *Phygadeuon trichops*
   Dr. E. Naton, Bayerische Landesanstalt für Bodenkultur und Pflanzenbau, Abteilung Pflanzenschutz, Postfach 38 0269, D-8000 München 38
4. *Chrysopa cameo*
   Dr. F. Bigler, Eidgenössische Forschungsanstalt für landwirtschaftlichen Pflanzenbau Zürich Reckenholz, Postfach, CH-8046 Zürich
5. *Syrphus vitripennis*
   Dr. W. Rieckmann, Pflanzenschutzamt Hannover, Wunstorfer Landstraβe 9, D-3000 Hannover 91
6. *Drino inconspima*
   Dr. Pa Huang, Niedersächsische Forstliche Versuchsanstalt, Abteilung B-Waldschutz, Gritzelstraβe 2, D-3400 Göttingen
7. *Phytoseiulus persimilis*
   Dr. Lise Samsøe-Petersen, Statens Plantevornscenter, Lottenborgvej 2, DK-2800 Lyngby, Denmark
8. *Encarsia formosa*
   Dr. P. A. Oomen, Plantenziektenkundige Dienst. Biologisch Laboratoriumonderzoek Bestrijding Ziekten en Plagen, Geertjesweg 15, Wageningen, The Setherlands
9. *Amblyseius porenrillae*
   Dr. W. P. J. Overmeer, Universiteit Amsterdam, Laboratorium voor Experimentele Entomologie, Kruislaan 302, Amsterdam, The Netherlands
10. *Leptomastix dactylopii*
    Professor Dr. F. Viggiani, lnstituto di Entomologia Agraria, Universita di Napoli, 1-80055 Portici, Italy
11. *Cryptolaemus montrouzieri*
    Miss J. Brown. Wye College, Ashford, Kent, England
12. *Anthocoris nemorum*
    Mr. S. I. Firth, East Malling Research Station, Maidstone, Kent, Me19 6BJ, England
13. *Opius* sp.
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INSECTICIDE SPECIFICITY: INTRINSIC SELECTIVITY AND OPTIMIZATION[1]

M. Shepard and T. M. Brown[2]

Insecticide selectivity results from the intrinsic toxicity of the material and from various operational factors. Although most chemical insecticides are toxic to a wide range of target and nontarget species, there is an array of materials which can be selected for use in a pest management program with selectivity favoring mammals, fish, and beneficial insects.

Populations of resistant pests can change drastically the intrinsic selectivity of an insecticide. In general, as pest susceptibility decreases due to resistance, selectivity favoring beneficial species is diminished. An approach to inducing selectivity is to modify insecticide chemistry.

Using synergists can enhance the selectivity of certain insecticides. Applying conventional insecticides to insect populations on resistant host plants can also be effective. Systemic materials can greatly enhance selectivity against insect pests, but often severely injure beneficial species.

Changing certain operational factors, for example, changing the formulation from emulsion to dust and granules preserved spiders, although more active ingredient was used. Insecticides placed at specific sites (root zone) increase their effectiveness and selectivity. Applications of granules to the nursery box containing rice seedlings are reported to be an effective and labor-saving approach for control of planthoppers and leafhoppers. New application techniques, such as the control droplet application (CDA) and electrostatic sprayers, could have a major impact on development of economically and environmentally sound methods of rice insect control by using low rates and obtaining better coverage.

Careful timing of insecticide applications can significantly reduce the amount of material used and increase selectivity. A thorough knowledge of pest and beneficial insect population dynamics is needed to exploit this approach. Practical insect survey techniques for timing applications and assessing the results are equally important. Sequential sampling plans have excellent potential and should be developed for all major rice pests and perhaps several beneficial species.

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INTRINSIC SELECTIVITY

Insecticide selectivity for rice pest control is due to intrinsic and operational factors. Intrinsic factors relate to the innate toxicity of the insecticide to the pest and to nontarget organisms. These factors are fundamental to selectivity. Operational factors such as formulation, application method, insecticide placement, dosage, and timing are important also and can be manipulated to achieve optimum selectivity.

Selectivity favoring vertebrates

The intrinsic selectivity of an insecticide is obtained by dividing the median lethal dose for the nontarget species by that for the target pest. Compounds which selectively favor nontarget species have values greater than one. A value of 10 indicates that the insecticide is 10 times more toxic to the pest than to the nontarget species when both are exposed to the median lethal dose for the pests.

Selectivity ratios for many insecticides have been calculated for the white Norway rat, representative of the nontarget mammal, and the housefly (Hollingworth 1976). Among conventional insecticides, which affect the nervous system, there is a wide range of intrinsic selectivity favoring mammals (Table 1). Permethrin is very remarkable in this characteristic, but carbofuran, an important insecticide for insect control in rice, has no intrinsic selectivity favoring mammals. Operational factors such as formulation and site of application minimize the carbofuran hazard so that the chemical can be used without harming mammals.

In fish, represented by the rainbow trout, permethrin is not very selective (Table 1) and it is nearly 1,000 times more toxic than methyl parathion. It is evident that selectivity favoring fish must be considered separately from that favoring mammals.

Although these comparisons may not apply directly to rice pests, they are useful models. This is especially important when generalizations can be supported by theory. For instance, many organophosphorus insecticides have less selectivity favoring mammals because of a lack of arylester hydrolase in most birds which results in much less organophosphate detoxicative capacity (Brealey et al 1980).

Selectivity favoring beneficial insects

When the nontarget species are the natural enemies of rice pests, then selectivity becomes especially relevant. Pyridafenthion and tetrachlorvinphos are exceptionally selective, favoring the wolf spider *Lycosa pseudoannulata* while being toxic to its

Table 1. Selectivity favoring vertebrates for several common insecticides.

Insecticide	Selectivity, quotient of median lethal doses	
	Rat/housefly[a]	Trout/*Culex* mosquito larva
Permethrin	2143	3.2[b]
Fenthion	107	1.6[c]
Methyl parathion	20	5.1[c]
Carbofuran	0.9	–

[a]Hollingworth 1976. [b]FMC Corporation 1980 and Priester and Georghiou 1980. [c]Brown 1978.

Table 2. Selectivity favoring natural enemies of rice pests for some insecticides (Takahashi and Kiritani 1973).

Insecticide	Selectivity, quotient of median lethal doses	
	Lycosa/Nephotettix	*Conocephalus/Chilo*
	Organophosphorus insecticides	
Pyridafenthion	>955	0.44
Tetrachlorvinphos	>474	1.8
Malathion	2.7	0.19
Diazinon	1.5	0.28
Fenitrothion	0.20	0.16
Fenthion	0.036	1.6
	Carbamate insecticides	
Carbaryl	2.3	–
BPMC	0.79	–
MIPC	0.30	–
Methomyl	0.28	0.036
	Other insecticides	
Lindane	.0094	0.18
Cartap	–	12.0

prey, the green rice leafhopper (Table 2). Lindane and fenthion are just the opposite, selectively favoring the pest.

For the grasshopper *Conocephalus maculatus,* which feeds upon eggs of the rice stem borer, only cartap is greatly selective in favor of the predator (Table 2). Tetrachlorvinphos exhibited a selectivity value of 1.8 and is the only organophosphorus insecticide benefiting both of the representative natural enemies in these comparisons.

Resistant populations of pests can render these estimates inaccurate; therefore, tests of local populations are necessary for species commonly exhibiting insecticide resistance. For example, if we assume that the wolf spider has not developed resistance, then the selectivity of carbaryl was lost in Nakagawara, Japan, in 1970 and in Dah-li, Taiwan, China, by 1980 because of developed resistance in the green rice leafhopper (Table 3). Although resistance in natural enemies appears less common than in pests, selectivity could be restored through introduction of resistant predators, as has been done with organophosphorus-resistant predatory phytoseiid mites in apple orchards (Croft 1982).

The comparisons in Table 2 must be extended to the newer categories of insecticides, especially the photostable pyrethroids and the chitin-synthesis-inhibiting compounds such as diflubenzuron. Among insects found in cotton, the pyrethroids are selective in favor of the predator *Chrysopa carnea* Stephens, when its susceptibility is compared with that of *Heliothis virescens* (Fabricius), the tobacco budworm. Pyrethroids are not selective when the natural enemy is *Campoletis sonorensis* (Carlson), a parasite of the tobacco budworm (Radakulendran and Plapp 1982). Again, it has been observed that insecticide resistance in both pests and natural enemies will be a primary factor in pyrethroid selectivity in apple orchards (Croft 1982).

Table 3. Relationship of insecticide resistance in a rice pest to selectivity.

	Nephotettix, median lethal dose, mg/kg carbaryl	Resistance ratio	Selectivity[a] *Lycosa/Nephotettix*
Japan[b]			
Miyagi, 1969	0.71	–	24
Saga, 1970	5.3	7.5	3.2
Yoshida, 1971	22	31	0.75
Nakagawara, 1970	71	100	0.24
China, Taiwan[c]			
Hsin-chu	8.3	12	2.0
I-lan	9.9	14	1.7
Chang-hau	33	47	0.50
Tai-ping	54	77	0.31
Mei-nung	55	78	0.30
Dah-li	56	79	0.30

[a]As in Table 2, *L. pseudoannulata* is assumed to be uniformly susceptible. [b]Asakawa and Kazano 1976. [c]Kao et al 1982.

Development of insecticides with enhanced selectivity

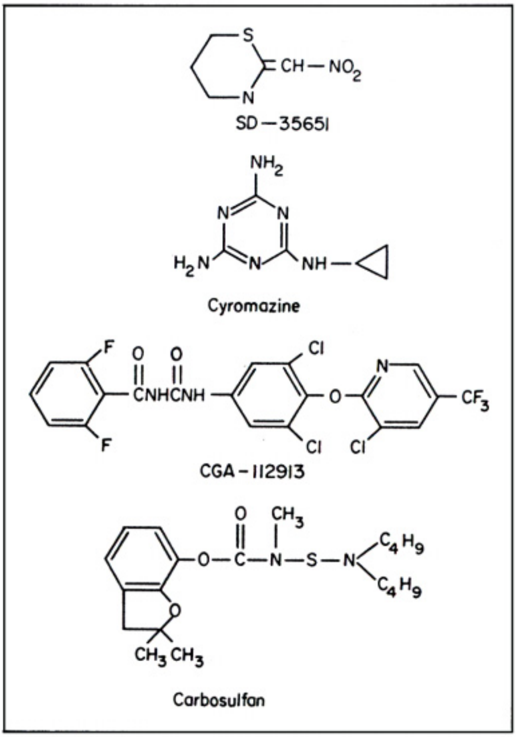
Insecticides which attack the nervous system can be selective if they reach the target more readily in insects than in vertebrates. Permethrin is detoxified more rapidly in mammals than in insects (Shono et al 1979); however, other pyrethroids which are metabolized less rapidly are much more toxic than permethrin in mammals.

Conventional insecticides can be modified to increase selectivity. A current example is the sulfinylation of carbamate insecticides to produce derivatives with greater selectivity favoring mammals (Table 4). A commercial product of this type is carbosulfan (Fig. 1) which is a di-*n*-butylaminosulfenyl derivative of carbosulfan; it is activated to carbosulfan in the rat (Umetsu and Fukuto 1982).

Novel insecticide chemistry should be evaluated for rice insect control and for selectivity. An example is SD-35651, a nitromethylene heterocycle (Fig. 1, Ross and Brown 1982). Shell Kagaku is testing SD-35651 and its derivatives in rice in Japan. This compound has plant-systemic insecticidal activity and it probably acts as an acetylcholine mimic with similarity to cartap (Flattum 1982).

Table 4. Improvement in selectivity favoring mammals in derivatized carbamate insecticides (Fahmy and Fukuto 1981).

Insecticide	Median lethal dose (mg/kg)		Selectivity	Selectivity increase in derivative
	Mouse	Housefly	Mouse/housefly	
Aldicarb	0.5	5.5	0.09	–
(*n*-decyloxy)sulfinyl aldicarb	60	11.5	5.2	57-fold
Carbofuran	10	6.7	1.5	–
(*n*-butylthio)sulfinyl carbofuran	450	16.5	27.3	18-fold
Methomyl	10	3.7	2.7	–
(*t*-butylthio)sulfinyl methomyl	135	5.5	24.5	9-fold



1. Novel insecticides to be evaluated for selectivity.

Selectivity is enhanced greatly in insecticides acting on targets unique to invertebrates such as chitin synthesis, which is inhibited by diflubenzuron, and metamorphosis which is blocked by juvenile hormone mimics. In most cases, these insect growth regulators have an intrinsic selectivity greater than 5,000 favoring mammals.

Cyromazine (Fig. 1), the first triazine insecticide, is being developed for vegetable insects as Trigard by Ciba-Geigy Corporation (Ross and Brown 1982). Because cyromazine has activity against the tomato pinworm *Keiferia lycopersicella* (Walsingham) and the vegetable leafminer *Liriomyza sativae* Blanchard, it should be worthy of examination against similar lepidopterous and dipterous rice pests. This unique insecticide may act as an insect development inhibitor causing deformed, elongated pupae in houseflies, although it is not a juvenile hormone mimic nor are its effects the same as those of diflubenzuron.

Diflubenzuron is exceptionally insecticidal when ingested by certain lepidopterous pests. It was the most active of 26 insecticides tested in the diet of *Spodoptera frugiperda* (J. E. Smith), the fall armyworm (Ross and Brown 1982). Several related compounds are in development for agriculture, including CGA-112913 from Ciba-Geigy which is also IK17899 from Ishihara. It bears a substituted pyridinyl-oxy moiety added to a diflubenzuron-like structure (Fig. 1). None of these insecticides are systemic.

Although the photostable pyrethroids are very toxic through contact exposure.

SD-35651, cyromazine and diflubenzuron are both most effective when ingested. Insects ingesting treated plant surfaces receive the greatest exposure.

Another method of improving selectivity is to add a synergist to the insecticide. This is advantageous if the synergistic action is greater in the pest than in the natural enemy. For example, in Japan IBP (Kitazin-P) fungicide and other organophosphates have been used as malathion synergists against malathion-resistant *N. cincticeps* and *Laodelphax striatellus* (Hama 1980). Similarly, insect-resistant plants can be used interactively with insecticides by increasing pest susceptibility. Kea et al (1978) showed that field populations of *Heliothis zea* larvae in soybean were much more susceptible to both biological and chemical pesticides when they fed on resistant soybean foliage (Table 5). Increased selectivity should result because these techniques are less likely to influence the susceptibility of the natural enemies.

Many insecticides developed recently are especially important against lepidopterous pests; however, these are often less effective against heteropterous pests which have become important in rice (Kiritani 1979). In Japan, an array of carbamate insecticides has been very important against planthoppers and leafhoppers. Close scrutiny of the quantitative structure-activity relationships of these compounds in the major heteropterous pests and their natural enemies will provide a better basis for optimizing selectivity. For example, 3-*t*-butylphenyl N-methylcarbamate was most inhibitory of 53 phenyl N-methyl carbamates against acetylcholinesterase of *L. striatellus* heads (Kamoshita et al 1979). Similarly, detailed studies in predators can be applied to advanced design of selective carbamate insecticides.

Basic research is needed to find unique targets in pests so that intrinsic selectivity can be ensured from the onset of insecticide development. A potential application may exist in the presence of D-alanine in heteropterous insects (Ayers et al 1974). If this unusual amino acid is vital, and if its synthesis or bioconversion can be blocked, then perhaps a very selective insecticide can be developed from a biochemical curiosity.

The development of an insect growth regulator for heteropterous pests of rice may be more practical. Juvenile hormone mimics and antagonists are characteristically active in these insects; however, practical application has been limited to glasshouse use of kinoprene against whiteflies and aphids (El-Ibrashy 1982). Modification of chemistry or formulation can produce a useful and selective insecticide for rice.

Although compounds may exhibit a broad range of toxicity, selective action may be gained when they are absorbed by plant foliage applied as sprays or to the soil where they are taken up by the roots and translocated to other plant parts. Although systemic materials offer some selectivity against phytophagous species, their impact

Table 5. Effect of interaction of resistant soybean genotype and insecticides on percentage of mortality of *Heliothis zea* larvae (Kea et al 1978).

Soybean genotype	Mortality (%)	
	Methyl parathion (0.035 kg ai/ha)	*B. thuringiensis* (2.2 × 10^9 IU/ha)
Bragg (susceptible)	25.0 a	6.2 a
ED73-371 (resistant)	56.6 b	67.8 b

on beneficial species, via feeding on poisoned pests or directly by limited feeding on the plant, is often significant. In addition, reduction of host populations to levels which cannot sustain a reserve of natural enemies is almost a sure prerequisite to pest resurgence. For example, side-dress applications of aldicarb for controlling the boll weevil *Anthonomis grandis* in cotton caused an 80% reduction in predator populations with a concurrent sixfold increase in populations of *Heliothis* sp. larvae when treated plots were compared with untreated control plots (Ridgway 1969).

Even though systemic compounds are often less selective than desired, they are useful in situations where nonsystemic insecticides are not practical. An example is carbofuran used in rice ecosystems. Serious attention should be given to the direct and indirect effects of carbofuran on predators and parasites, particularly from the standpoint of how the material may affect the population dynamics of pest and beneficial interaction.

OPTIMIZATION OF SELECTIVITY

Formulation

The first procedure to make an insecticide more selective is to change its formulation. Although this may not always be practical, changing the formulation from emulsion to dust or granules in rice systems has saved a significant amount of labor and reduced drift. Granules were found to be less toxic to spiders, although the amount of active ingredients (ai) was increased (Kiritani 1972). Although a systemic compound applied as granules may be innocuous to predators and parasites, mortality may result if the beneficials attack pests which have fed on the insecticide. Cartap granules at 1.2 or 2.4 kg/ha affected predation by *Lycosa* but chlordimeform at 0.9 kg/ha did not affect this spider through the food chain (Kiritani and Kawahara 1973). Interestingly, effective control of *N. cincticeps* was obtained up to the tillering stage of rice when an ai range from 0.5 to 2.0% was contained in the carbamate insecticides (MTMC, BPMC, MPMC, and NAC) (Kiritani 1976).

Application of 1% and 2% dust of BPMC did not significantly affect the population of total spiders, but *L. pseudoannulata* populations declined after ai concentration of BPMC was increased from 1 to 2%. Changing to application of granules to nursery box versus conventional control with dust significantly reduced the incidence of rice dwarf virus, which is transmitted by *N. cincticeps* (Kiritani 1976).

Bowling (1957) suggested that using a fertilizer-insecticide mixture could greatly reduce application costs and Koyama (1979) reported that insecticides are often mixed with fungicide to control several pests at one time.

Application

Insecticide placement. Before insecticide placement can be fully exploited, the necessary formulation must be available. One application of 50 g/box of 5% granules of ethylthiomethon 2 days before transplanting effectively controlled the rice dwarf virus transmitted by *N. cincticeps* (Kiritani 1976). There are several other reports of nursery box applications of granules including disulfoton for the brown planthopper (BPH), MIPC for leafhoppers, and diazinon and disulfoton for

N. cincticeps (Moriya 1978). A major advantage of this technique is that only about half of the conventional dose is used (Endo and Masuda 1978). Heinrichs and Valencia (1981) reported that granular insecticides placed in gelatin capsules and injected into the root zone of potted rice plants provided good control of BPH and green leafhopper (GLH).

Examples of precise insecticide placement are available in other crops. For example, in maize several seed-feeding insects are controlled by seed treatment with dieldrin at 1.3 g/kg of seed. Similar control using broadcast treatments requires 180 times as much insecticide (Metcalf 1974).

Cost of insecticide applications for controlling the rice water weevil was reduced in the US by seed treatment (Bowling 1957). Grape colaspis and rice water weevils were controlled using seed and soil treatments (Rolston and Rouse 1960). Such application is not only easier but seeds are protected from insect attack during storage.

Root zone application of systemic materials greatly lengthens residual activity of insecticides. Heinrichs et al (1981) reported that one carbofuran application in the root zone at transplanting provided insect control and resulted in yields either equal or superior to those obtained with foliar sprays.

Insecticide applications in China are made only in fields with damaging insect populations or infested spots within a field (Chiu 1979). This greatly conserves the natural enemy complex and prolongs an insecticide's use before resistance develops.

Application techniques. More than 95% of the insecticide used misses the target species. Ultra-low-volume (ULV) techniques have greatly improved this situation. In some instances, ULV applications of malathion and fenitrothion effectively controlled the rice stink bug *Oebalus pugnax* in Louisiana when compared with conventional application methods (Oliver et al 1971). However, there are drift problems when using ULV. A control droplet application (CDA) technique is currently being tested at IRRI (Heinrichs et al 1981). This hand-held, battery-powered apparatus allows a small amount of insecticide to be carried and applied in small droplets without the added weight of the diluent.

More recently, attention has been focused on electrostatic sprayers. Developed and marketed by the ICI Plant Protection Division as Electrodyn, this machine controls the droplet diameter (as with CDA) and produces charged particles which enhance coverage and reduce drift. The elecrostatic sprayer reportedly provides uniform droplet distribution through mutual droplet repulsion. Thus, there is a significant reduction in overspray and runoff (Coffee 1981). The machine has no moving parts, is battery powered, and can be hand-carried or vehicle-mounted.

A similar electrostatic sprayer is sold by FMC and can be mounted on a conventional high-clearance sprayer unit. Manley (1982) reported that application of insecticides by the FMC sprayer provided adequate insect control in cotton and saved about $50/ha in insecticide costs. By reducing the overall pesticide load on the rice ecosystem through better foliage coverage and reduced drift, this sprayer may have utility against selected rice pests.

Seedling dips with trichlorfon, dimethoate, or chlordimeform were effective against the yellow stem borer and gall midge. Chiu (1979) reported that one *root zone* application of pyrimioxythion at 15 kg/ha also gave effective control of the gall midge with no detectable effect on natural enemies.

Dosage. The insecticide use trend in rice pest management should be toward lower rates of more selective chemicals. Application should be carefully timed to provide the least disruptive influence on the environment and natural control agents. However, in Japan frequency of pesticide application doubled during the 1950s and 1960s.

Kiritani (1976) reported that 1/10 to 1/5 of commercial rates of chlordimeform could practically control *C. suppressalis.* Some of the effectiveness of this compound at these low rates may be due to some antifeedant action. One half of the ethylthiomethon dosage (50 g/box of 5% granules) 2 days before transplanting was sufficient to prevent transmission of the rice dwarf virus by *N. cincticeps.* The frequency of pesticide applications could be reduced in rice fields by 2-3 times for early rice crops and 4-5 times for middle-season crops without reducing yields (Kiritani et al 1972).

Examples of using minimum insecticide rates for insect control can be found in several other cropping systems. Major reductions in recommended insecticide rates for soybean insect pests came about through work by Turnipseed (1972) and Turnipseed et al (1974). They found that low rates of methomyl, carbaryl, and methyl parathion greatly conserved major naturally occurring predators, such as *Nabis* spp. and *Geocoris* spp. while providing adequate control of several lepidopterous pests.

It is important to realize that 100% pest control is not necessary to prevent economic loss. The degree of insect control required and the potential for natural control must be weighed. The successful use of minimum insecticide rates is linked to a sound understanding of damage thresholds and sampling methodology for determining the proper application timing.

Timing. Irrespective of chemical type, formulation, or application method, careful application timing is the simplest way to enhance insecticide effectiveness. Kiritani (1972) suggested that appropriate timing will achieve insecticide specificity. To focus on the most susceptible stage of a pest, a thorough understanding of its seasonal population dynamics is necessary. Serious consideration should be given to the ecology of beneficial species to avoid material application at a time when they may be making a significant pest control contribution.

Heinrichs et al (1981) suggested that, based on light trap catches and field surveys, the best time to spray for BPH is about 2 weeks after peak trap catches, provided the economic threshold has been reached. In addition, one insecticide application for control of third and fourth instars of the second generation was more effective than calendar applications. In China, foliar sprays for control of the yellow stem borer *Scirpophaga incertulas* and leaf folder *Cnaphalocrocis medinalis* were more effective during egg hatch than during peak adult emergence (Chiu 1979).

Careful application timing could significantly reduce the amount of material used, allowing survival of a larger proportion of beneficial and other nontarget organisms. In nonrice crops, Croft and Brown (1975) found timing to be important in Michigan apple orchards where compounds, only moderately toxic to the predatory mite *Amblyseius fallacis,* were applied during April to mid-June when most of the mites are on the ground and less likely to encounter the pesticides.

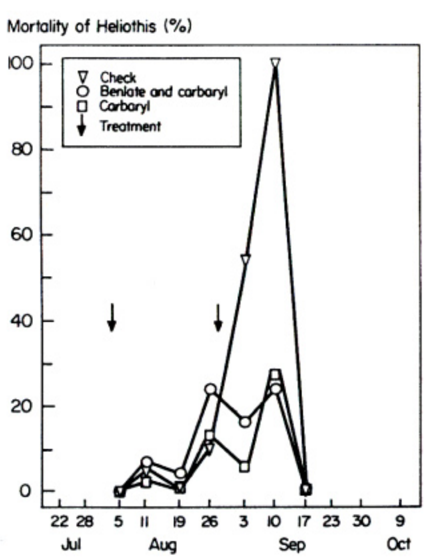
Kiritani (1972) showed that control of the first generation of *C. suppressalis* had no effect on yields. It is likely, however, that efforts to control this generation had a significant effect on the natural enemy complex.

In the southeastern US, improper timing of early applications of methyl parathion in soybeans almost always causes dense populations of several insect pests to develop later in the season (Shepard et al 1977). The relationship between timing of an insecticide application and resurgence of pest populations should be determined for all major insect pests of rice and insecticides used for their control. For soybeans in the US, two applications of the fungicides benomyl (Benlate), fentin hydroxide (DuTer), and chlorothalonil (Braco) and the insecticide carbaryl were sufficient to reduce *Heliothis* mortality caused by the entomophagous fungus *Nomuraea rileyi.* Response of this entomopathogen to Benlate-carbaryl combinations and to carbaryl alone is shown in Figure 2. Selectivity of these pesticides was improved when they were applied after *N. rileyi* epizootics occurred in the field or before the *N. rileyi* was detected (Horton et al 1980).

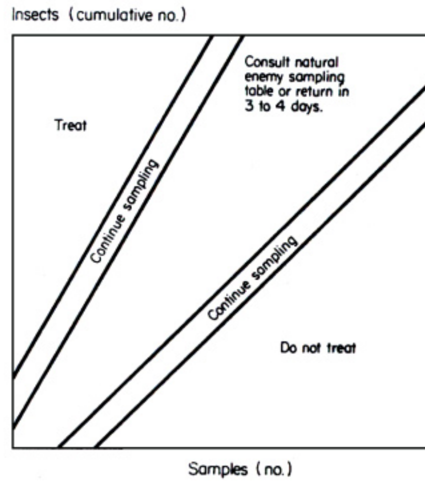
Methyl parathion and deltamethrin caused populations of BPH to resurge when these compounds were applied as sprays 50 and 60 days after rice was transplanted, but earlier applications caused no resurgence (Heinrichs et al 1982).

A logical first step in enhancing insecticide selectivity based on timing is to establish baseline information about the susceptibility of various life cycle stages of pests and beneficials to different chemicals, application rates, and formulations. Examples are reported by Heinrichs and Valencia (1979, 1981), Kiritani (1972, 1976), and Puissegur (1976).

Recent technological advances have resulted in computer simulations of the life history of certain pests (Sasaba 1974, Hokyo 1976). These models may have predictive value and should provide insight into proper timing and pest population response. Sound sampling and monitoring programs should be developed to provide inputs for these sophisticated models and to ensure that the simulation adequately describes the behavior of field populations.



2. Effect of carbaryl and carbaryl-Benlate treatments on mortality of *Heliothis* caused by the entomogenous fungus *Nomuraea rileyi* (Horton et al 1980).



3. Generalized sequential sampling for timing insecticide treatments which could include natural enemies

For short-term decision making about pest treatments, sequential sampling plans have become important in many insect pest management programs (Pieters 1978). The three basic requirements for model development are 1) insect distribution, 2) the risk level the grower is willing to take, and 3) the damage threshold. Development and use of a sequential sampling model could greatly improve application timing and assessment of results. A generalized sequential sampling model which incorporates natural enemies is shown in Figure 3.

Formulas for developing sequential sampling plans are found in several references including Waters (1955) and Shepard (1980). A sequential sampling program for natural enemies can be developed by analyzing population curves for several years to classify their populations into low, medium or high. Waddill et al (1974) have done this for *Nabis* spp. and *Geocoris* spp., two major predator groups in soybean.

The major advantage of sequential sampling is the tremendous savings in time over other methods. The sample size is not fixed, so that when populations are low or high, very few samples are needed. Flexibility can be added by programming the plans into a hand-held programmable calculator. Any changes in risk level or damage thresholds can be made immediately and a new sequential sampling plan can be produced. Models for the TI-59 (Texas Instruments) calculator, which include the Poisson, negative binomial, and binomial distributions, have been developed and are available from the senior author.

Use of insecticides which are physiologically and ecologically selective should continue to be the major objective in developing integrated pest management programs for rice. Although the vast majority of current insecticides are relatively broad spectrum compounds, the practical approach to making them more selective is associated with manipulating formulations, application rates, timing, etc. In many instances, development of ecologically and economically sound control programs is limited by our lack of knowledge of the interaction of the pests, crops, and natural enemy complexes.

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TECHNIQUES FOR EVALUATING AND SCREENING INSECTICIDES

BASIC METHODS FOR EVALUATING AND SCREENING INSECTICIDES

B. Sechser

Insecticide screening identifies commercially usable chemicals according to biological effectiveness and environmental impact. Screening techniques are becoming standardized as governments and international bodies exert their influence.

Initial laboratory screening is a compromise to reduce the number of potential candidates before more expensive field screening. The methods should be fast, cheap, and related to field conditions, but less rigorous without missing any important compounds. Laboratory techniques and guidelines on complicating factors exist to test chemicals acting as stomach or contact poisons, fumigants, chemosterilants, microbial agents, juvenile hormones and mimics, chitin inhibitors, pheromones, and systemic poisons. Criteria for promotion of candidates to field testing include comparable performance on standard targets, safety, rapid metabolism, low toxicity to beneficials, and economic feasibility.

Field testing compares candidates with standard products and controls under close to realistic conditions. The parameters investigated include spectrum of activity, residual activity, crop tolerance, rates, formulation, application, waiting periods, and cost performance. Establishing good field trials is a matter of experience, and influential factors include environment, local standard check treatments, untreated controls, plot size, replication number, application techniques, and volume applied. The distribution of insect populations should not be uniform and precounts help in the proper allocation of plots through randomization. Data collection is also a compromise between statistical purity and cost consideration. The criteria of assessment for primary trials are degree of infestation and damage, but later trials must include data on yield and economic costs and returns. These data are the definite aim of all testing.

DISCUSSION

MAGALLONA: We have discussed the desirability of avoiding massive pesticide use. Is aerial application discouraged or promoted by your company?

SECHSER: In product development, aerial application is not considered. Aerial application was widely used on cotton in Brazil 10 years ago but is now much less common.

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LABORATORY AND FIELD TESTS FOR EVALUATING AND SCREENING INSECTICIDES AT IRRI

E. A. Heinrichs and O. Mochida

Laboratory tests for evaluating and screening insecticides at IRRI are done with actual target pests using standard methods. Insecticides that pass the laboratory screening tests are then evaluated in field trials.

Laboratory screening

About 10 species of target pests are routinely used at IRRI and mass rearing methods for all of them have been developed. Most of the insecticides tested are in liquid formulations, but some are granular. Standard methods for contact toxicity exist for BPH, GLH, WBPH, and rice bug; methods using foliar sprays exist for BPH, GLH, WBPH, striped stem borer (SSB), yellow stem borer (YSB), leaffolder (LF), caseworm (CW), rice bug, and armyworm; a dipping method exists for armyworm. Broadcast techniques using granulars exist for BPH, GLH, WBPH, SSB, YSB, LF, CW, and armyworm; root-zone methods for hoppers and stem borers; and soil incorporation methods for the same targets as broadcasting. Fumigation, irrigation water treatment, seed treatment, root soaking, and root coating have been developed but not standardized. Chemosterilants, pheromones, insect growth regulators, bacterials, and botanicals are also tested. The methods for evaluating each of these kinds of insecticides are different and must be developed.

Field testing

Many ecological factors affect the quality of field testing of insecticides on rice. These factors include plot size, variety, site of field, choice of standard check insecticides, application methods, evaluation methods, and level of insect pressure. Methods for increasing insect pressure include planting time, fertilization, plant spacing, artificial lighting, insecticide-induced resurgence on neighboring plants. and artificial release or caging of insects in the field. Recommendations about insecticides should only be made after a review committee has evaluated the data collected under standard conditions. Standard conditions should be specified to include the number of sites and seasons data are to be collected, the untreated level of insect pressure that represents a valid test, the rates and volumes to be tested, and the application methods to be used, giving special importance to farmers' methods. Virus vectors require high levels of control. Effects on nontarget mammals and fish, persistence, and resurgence activity must also be examined.

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DISCUSSION

ISHIKURA: This morning's presentations discussed chemical screening techniques to identify candidates, evaluate the efficacy of these candidates on insect species, and field testing (which should determine the dosage, number, and time of applications). I would like to know how the data obtained in the laboratory can be translated to setting the dosage and number of applications in the field.

HEINRICHS: The relationship between the effectiveness of foliar sprays in laboratory and field tests varies depending on the insecticide and the environmental conditions under which it is applied in the field. Insecticides that have poor activity in laboratory tests are poor in the field. Some insecticides that are active in the laboratory are poor in the field. Laboratory testing simply eliminates the poor insecticides and narrows down the number to be field tested. Field testing must be conducted to set ratiosand determine the number of applications.

CHELLIAH (comment): 1) A spray volume of 1,000 liters/ha is too high and the standard should be established at a lower, more practical level. Alternatively, the concentration of active ingredient in the spray liquid should be standardized.

2) It is not desirable to standardize dosage at 0.75 kg ai/ha. Dosage should vary with the chemical.

3) It would be valuable to develop a factor relating efficacy in laboratory tests to subsequent performance in field trials.

ISHIKURA (comment): Field trials are primarily used to determine application parameters such as dosage, spray volume, timing, and number of applications. Translating the results of trials into performance under field control is still a major problem.

MONTRI: When assessing the persistence of chemicals, do you use bioassay or residual analysis?

HEINRICHS: Normally bioassay, because this is much cheaper.

MALIK: Is 85% mortality in field trials sufficient for the farmer? Should it be raised?

HEINRICHS: It depends on the initial level of pest infestation. We feel it is necessary, in accord with IPC concepts, to educate the farmer to tolerate the presence of pests at a low level.

PEREIS (comment): When considering pesticide economics, the cost over a whole cropping season, not for a single application, should be taken into account. When considering the pest infestation level necessary for a field trial to be valid. the population in the control should at least reach the economic threshold. In testing, we usually wish to calculate the cost-benefit ratio, but the cost is often unknown when materials are provided to the laboratory.

HEINRICHS (comment): Thresholds are not developed for all insects. Normally, the best available estimate is used.

SECHSER (comment): It is often difficult to obtain cost information at the testing stage since cost varies greatly according to the scale of manufacture and subsequent use pattern.

KENMORE (comment): It is difficult to take into account frequency of application when predicting cost. Using thresholds in an IPC program, it is impossible to predict the frequency of applications in a season. Economic evaluation is still vital but perhaps we should move toward establishing a maximum value of insecticide. This is biologically difficult but realistic.

BATEMAN (comment): I am surprised at the standard rate of 0.75 kg ai/ha; in Vietnam the standard is normally 0.5 kg ai/ha. IRRI reports are an important source of reference and perhaps it would be desirable if the dosages were halved.

HASSAN: How is the formulation and rate of application on your tests on potted plants related to rates recommended to farmers?

MOCHIDA: Our first evaluation is conducted at 0.75 kg ai/ha. If this rate proves effective. we test at lower dosages. The Philippine: Government recommends 0.75 kg ai/ha for all pesticides.

SADJI: Why are you considering the use of carbofuran as a check insecticide?

HEINRICHS: Carbofuran was originally used because of its broad spectrum of activity and high effectiveness. It is now less effective on the farm because of repeated use, either because of insect resistance or microbial degradation.

METCALF (comment): I am uneasy about the concept of recommendations, because it implies fixed action. The concept of IPC is dynamic and decisions should be taken in relation to the problem observed by the person involved in control procedures.

SANCHEZ (comment): The Philippines is moving toward IPC, though adoption by farmers is slow.

SECHSER (comment): In Switzerland, two recommendations are made, one specifically for IPC. In relation to earlier comments, I feel it would be difficult or impossible to establish a conversion factor for laboratory-to-field efficacy.

LABORATORY AND FIELD TESTS OF INSECTICIDES IN SOUTH KOREA

H. R. Lee

The selection of effective chemicals for rice crop protection is given very high priority in South Korea. Extensive studies on efficacy, timing, application methods, persistence, and phytotoxicity for major and minor pests have been made. Studies on insecticide resistance have been limited to major insect pests. Insecticide registration involves submission of data by industrial applicants through a Pesticide Industry Association and confirmatory trials by the Agricultural Chemical Research Institute under the Office of Rural Development. Registration includes field tests for efficacy and phytotoxicity, mammalian and fish toxicity, and residues (data can be submitted from foreign tests). Additionally, the insecticides are tested after two years of storage to check for changes in insecticidal activity and toxicity.

A total of 95 insecticides are registered for use on rice; eight are combinations of compounds. In fields where pest populations are higher than standard threshold densities, at least 80% control is required for registration. The system of inspecting marketed pesticides has been expanded from 500 to more than 3,000 samples per year in the past three years. Future trends include development of better techniques, stronger enforcement of quality control in marketed chemicals, and improvement of the registration systems by gradual assignment from public office to private agencies.

DISCUSSION

MOCHIDA: What kind of fish do you use for fish toxicity testing in Korea?

LEE: We use the common carp.

DANDI: Should every insecticide be officially tested for its toxicity to fish in the field?

LEE: No, laboratory data on fish toxicity are required for the registration of new insecticides.

CHELLIAH: Is there any special reason for adopting a threshold of 20 BPH/100 hills?

LEE: Control time depends on the BPH population. In our country, the BPH population reaches one generation after migrating in the early or middle part of August. The growth stage of rice is also important. We decided that when BPH population reaches 20/100 hills, the economic threshold will be reached. Also, we continue to study the economic injury levels for each pest of rice.

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CASTAÑEDA: Is it correct that South Korea prefers that the registration of pesticides be undertaken by a private office rather than by a government agency?

LEE: The association is not a government agency, but is authorized as an agency for handling registration affairs.

WEERAWOOTH: Are the eight insecticide mixtures recommended to farmers?

LEE: Yes, farmers like combinations to control all the pests at the same time.

DAVID (comment): The number of 95 pesticides for rice pest control seems to be too high.

LEE (comment): Our government lays stress on improving the production of rice as a major food staple. Also, this does not mean 95 active ingredients but 95 formulations.

LABORATORY AND FIELD TESTS OF INSECTICIDES IN JAPAN

T. Nagata

Two laboratory screenings are followed by field screening before field evaluation for registration. Simultaneous collection of data on mammalian and fish toxicity is followed by chronic toxicity and mutagenicity tests. Metabolic and residue tests are required, together with field tests by authorized agencies at three sites for two seasons. For each succeeding stage of the testing process, a greater percentage of the tests for the remaining candidates are conducted under realistic application methods against actual target pests.

DISCUSSION

DANDI: Do you have more than one association involved in the registration of pesticides?

NAGATA: Two; the Japan Plant Protection Association (JPPA), mainly for insecticides and fungicides; and the Japan Association for Advancement of Phytoregulators for herbicides and others.

DANDI: 1) Which one does the field evaluations? What is the role of JPPA? 2) How is the relation between government institutions and JPPA in relation to the data obtained as mentioned in item 1?

ISHIKURA: The role of JPPA in producing the efficacy data of pesticides is to allocate field trials to both national and regional experiment stations and carry out the field trials with the cooperation of research workers at these stations. The results of the field experiments are given to the Experimental Committee of the Association, which evaluates, and if appropriate, uses them as the basis of recommendations. The recommendations are sent to the pesticide companies that contracted the conduct of field experiments. The pesticide companies submit the recommendations to the National Agricultural Chemical Inspection Station when they apply for the pesticide registration. If the recommendations are accepted, the pesticide containers are labeled accordingly.

ALAM: Do you use honeybees in the first laboratory trial?

NAGATA: In the first screening, no. The side effects of pesticide application are sometimes assessed in the field.

ISHIKURA (comment): Not many bees are found in Japan, so the registration is not so strict. In the first test, stored grain pests are also used, because they are easy to rear.

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LABORATORY AND FIELD TESTS OF INSECTICIDES IN BANGLADESH

S. Alam

Field tests, usually held under natural infestations of major insect pests, are the only methods used for screening insecticides in Bangladesh.

To improve the current evaluation and screening system, we adopted a method using an inexpensive hand-held atomizer originally developed at Tamil Nadu Agricultural University in India. We compared it with the Potter's spray tower technique for laboratory application of test chemicals. After 24 h, results between the techniques on *N. lugens* and *N. virescens* were not significantly different for decamethrin, BPMC, carbofuran, and distilled water. Although the atomizer takes longer to operate, its simplicity, portability, and low cost make it an attractive alternative.

DISCUSSION

CHELLIAH (comment): The atomizer cannot be compared in the strict sense with the Potter's spray tower. With the Potter's spray tower, the insecticide droplets are discharged uniformly on the target site. With the atomizer, however, the droplet size and discharge rate depend upon the speed at which the bulk is operated. The atomizer is more useful for spraying potted plants than for spraying anesthetized insects on a petri dish.

HASSAN: I would like to know more about the atomizer. Can it be used for WP formulation?

ALAM: Although we have not tested it with WP, it is possible that the atomizer could be used with WP.

SAXENA: Why is deltamethrin included in the evaluation test against the BPH? Deltamethrin is known to cause BPH resurgence in the fields.

ALAM: It was used with three other insecticides in a trial to determine the differences in performance between two treatment methods.

MOCHIDA (comment): Regarding the volumes of water for foliar sprays, our data show no difference in effectiveness among insecticides with 300, 500, 750, and 1,000 liters water/ha. We think that combinations of spray volumes and rates may produce different results in the control of pests.

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MONITORING PESTICIDE POISONING IN THE PHILIPPINES

C. Castañeda and N. Maramba

Monitoring is limited to patients admitted to government hospitals and reported by the Ministry of Health to the Fertilizer and Pesticide Authority (FPA). In a report from a Manila hospital, more than half of the poisoning cases were suicidal, more than 20% accidental, and fewer than 15% were work related. Data on chronic poisoning and from private physicians' patients were scanty. Organophosphates were the major cause of poisoning. The FPA developed training modules in pesticide safety for medical and paramedical staff of the Ministry of Health, agropesticide dealers, pesticide applicators, and farm technicians. Some studies on chronic exposure began with patients with aplastic anemia. Future needs are the imposition of regulations on pesticide safety, research on the epidemiology of poisoning, design of inexpensive and practical protective clothing and equipment, optimum safety measures in manufacturing plants, monitoring of farmers' health, residue studies in people, and close cooperation among the many agencies concerned with safe use of pesticides.

DISCUSSION

METCALF: To what extent is international experience on chronic pesticide hazards to humans taken into account in the banning of specific pesticides and uses in the Philippines? I am referring to the recent banning in the US of DBCF for male sterility, nitrogen for teratogenicity, leptophos for delayed neutrotoxicity, and Vacor rodenticide for induction of permanent diabetes. Surely, it is not necessary for each country to learn by human tragedy.

MARAMBA: In the Philippines, the evaluation committee of the FPA considers data from all over the world besides its own experiences. As a result, the list of banned and restricted pesticides is amended according to the most recent information.

MAGALLONA (comment): I think we should be more careful and not simply adopt the WHO classification. We should find out if the classification is applicable to our own situation. In the Philippines, the Masagana 99 program has adopted a cut-off for dermal and inhalation toxicity as a safeguard to our farmers.

MAGALLONA: What should be used as indicators of chronic poisoning?

MARAMBA/CASTAÑEDA: Many factors influence the expression of chronic poisoning. Resistant tuberculosis was found to be related to fibrosis induced by paraquat. Only by in-depth study was paraquat implicated as a causative factor. Normally it is extremely

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difficult to separate the factors, which might include malnutrition, infectious diseases, and other factors peculiar to the locality.

SAXENA (comment): Delegates might wish to study the new book — *"A growing problem", pesticides in the third world* published by Oxfam.

SAFE USE OF INSECTICIDES: REGISTRATION OF AGRICULTURAL PESTICIDES AND REGULATION OF THEIR USE IN JAPAN

H. Ishikura

In Japan, all agricultural pesticides require registration and their use is strictly regulated by the Agricultural Chemicals Regulation Law and several associated laws and rules. Total consumption of active ingredients for rice pest control in Japan for 1980 was 19,580 t of fungicides, 6,530 t of herbicides, and 12,560 t of insecticides.

Government agencies have been trying to reduce the intoxication of farmers mainly by developing less toxic pesticides and promoting group pest control, especially among rice farmers. The training of medical doctors in the emergency treatment of victims of agricultural pesticide intoxication has resulted in a dramatic decrease in fatal and nonfatal intoxication cases. From 1957 to 1980, fatal cases of pesticide intoxication dropped from 47 to 16, and nonfatal cases from 593 to 113.

DISCUSSION

BATEMAN: Farmers in the third world generally do not wear protective clothing. Is it possible to define a limit for oral or dermal toxicity above which a chemical should not be recommended for general field work?

ISHIKURA: In Japan, there has been a trend to use pesticides of lower toxicity as new compounds become available. In the field, dermal and inhalation toxicities are more important than oral toxicity. In general, a dermal toxicity value of 100 mg/kg may be excreted and still be considered relatively safe.

BATEMAN: When no protective clothing is worn?

ISHIKURA: No. Under those conditions, it would be too high. Thisdemonstrates that many factors are involved in the choice of a limit and it is probably not possible to set a categorical limit.

MARAMBA (comment): Mixtures of ingredients and solvents can influence toxicity. Potentiation studies are being requested in assessing toxicology data. Also, a distinction should be made between suicidal and accidental poisoning.

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EFFICIENT USE OF INSECTICIDES

INSECTICIDE APPLICATION METHODS IN JAPAN

T. Nagata

Most Japanese farmers apply pesticides with powered machines, primarily dusters, blowers, and convertible applicators. The most popular formulations are dusts, followed by liquid formulations for spraying, granules for broadcasting, and formulations for nursery-box application for use in transplanting machines. The nursery box treatment is effective for 30-50 days after transplanting, especially against virus vectors and feeders. More than half the rice-growing area in Japan was treated by helicopters in 1980; about half of it was treated with low- or ultralow-volume techniques.

DISCUSSION

SANCHEZ: The preference of Japanese rice farmers for dust formulated pesticides is striking. It is totally in contrast with what is happening in the Philippines and the rest of Southeast Asia where spray formulation is dominant. Why are dust formulations preferred in Japan?

NAGATA: The reasons are mainly socioeconomic. Although dust is more expensive, it can be applied readily with a pipe duster, a popular applicator in Japan.

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INSECTICIDE APPLICATION METHODS IN SOUTH KOREA

H. R. Lee

Over the last 10 years, use of pesticides on rice has increased in South Korea. Fungicide and herbicide use has increased faster than insecticide use. The total cost of rice pest control grew from less than $2 million to about $5 million in the last 10 years. In the last five years, the fraction of farmers using machine-powered applicators increased from 18 to 31%. The area covered by aerial application increased slowly while the cost increased rapidly. Surveillance systems give farmers information on insect and disease incidence. Farmers use recommended mixtures of pesticides to control insects and diseases simultaneously.

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INSECTICIDE APPLICATION METHODS IN THE PHILIPPINES

J. Sumangil

A 1975 survey of 138 farmers in two of the heaviest rice-producing provinces of the Philippines showed that 70% owned knapsack sprayers. Slightly over half of the sprayer owners were trained on sprayer use, and most claimed that they followed the recommended practices, though only 25% knew the meaning of active ingredient. Nearly half sprayed upon any appearance of pests, 25% used a calendar-based schedule. and less than 10% used thresholds. Over 60% did the spraying themselves. and about 25% hired others to spray.

Most farmers stored pesticides in their house, disposed of the excess in irrigation water or by burning, and wore long-sleeved shirts as their only protective clothing. More than 90% washed and changed clothes immediately after spraying.

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INSECTICIDE APPLICATION METHODS IN BANGLADESH

S. Alam

About half of Bangladesh's rice is treated with insecticides in any given season. Insecticides were distributed free from 1959-1974 and at 50% of their price until 1979. Since then, insecticides have been sold through commercial dealers. Only 16 insecticide compounds are registered for rice in Bangladesh. Three-fourths of all pesticide applications are made on rice, and about 200,000 ha are sprayed aerially each year by the Plant Protection Directorate. About 10,000 sprayers are being used in Bangladesh. Most are locally manufactured knapsack sprayers, that are kept in poor condition. Many farmers use brooms, leaves, and plunger pumps because the sprayers are unusable. Few safety precautions are observed. No application training courses exist. Research is focused on thresholds and practical recommendations.

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RESEARCH ON INSECTICIDE APPLICATION METHODS

G. A. Matthews

The major problem with hydraulic spraying is the large range of droplet sizes, which increase loss through sedimentation and evaporation. Correct choice of nozzle and uniform pressure can greatly improve existing knapsack application.

Controlled droplet application (CDA) can reduce dosage requirements by 30-400%, compared with knapsack spraying, by narrowing the spectrum of droplet size. It will thus not only reduce waste but also save time and labor. Its major drawbacks are the recurrent costs of batteries and special formulations. Researchers are attempting to reduce the energy required. Small droplets allow a reduction in the total volume of spray, but narrow swath widths are necessary to allow for change in wind speed and direction.

Electrostatic spraying reduces drift while retaining a small droplet size and a narrow spectrum of sizes. It also eliminates moving parts (i.e., the spinning disc of CDA) but requires special semiconducting formulations. Coverage of upper crop canopies is excellent but penetration is poor because the charged particles stick to the first grounded surface they strike. This is a source of ecological selectivity: if pests live on the upper canopy while natural enemies live below, the distribution of spray favors the natural enemies. Rice leaffolder and GLH are thus potential targets, but BPH seems less susceptible. Precise timing of spraying and accurate information on the migration of BPH and its natural enemies, however, may make adequate control possible. Applications must be made when the natural enemies are below the canopy and BPH is still in the canopy tops after immigration.

The simplicity and ecologically precise control possible with electrostatic sprayers are exciting, but further research is required. In addition, special formulations must be made available in their packaged form at the farm level.

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FORMULATION, DOSAGE, AND APPLICATION TECHNIQUES RELATED TO CROP STAGES

J. A. Litsinger and F. F. Sanchez

Because farmer acceptance of new concepts is slow, it is easier to change technology than force farmers to adopt our methods. To maximize the effectiveness of insecticides, such factors as formulation, dosage, and application methods must be improved.

Emulsifiable concentrates (ECs) are inexpensive, easy to transport, and can be applied as foliar sprays on any postemergence crop stage. Those are the main reasons why ECs are popular with farmers. The slow acceptance of seedling dips and soil incorporation of granules may be explained by the farmers' unwillingness to take risks, and their lack of cash.

No technology has replaced the knapsack sprayer, because replacement applicators are prohibitively priced and do not improve penetration of the pesticide into the rice canopy. The knapsack sprayer needs more safety improvements. Its performance may be improved by better nozzles. Minimum effective spray volumes should be determined in relation to crop stages. Most farmers apply spray volumes of 200-300 liters/ha in rainfed areas and 300-400 liters/ha in irrigated areas.

Recommended dosages should give the greatest impact in the shortest time (minimum effective dosage). Various national rice programs recommend application rates (e.g., in the Philippines 0.1-0.3 kg ai/ha). These low levels should be areas for efficacy testing and subsequent review of use recommendations.

The use of mixtures should be discouraged and must be regarded as a last resort, especially where resistant insect populations exist. The use of slow-release formulations should be discouraged because continuous release of insecticide during the entire cropping season may lead to more rapid development of resistance and is wasteful at growth stages when no pests occur.

DISCUSSION

SADJI: If we have to apply carbofuran, which do you recommend, liquid formulation or granular formulation?

LITSIVGER: Granular formulations are only effective during the vegetative stage when paddy water is present in the field. During this period, granules generally give superior control compared to sprayables. However on older plants, sprayables are superior to granules.

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ISHIKURA (comment): Formulation selection should be not only by efficacy but by the labor required for application and the safety of application to farmers. EC is generally more effective in control, but the application requires much labor. EC is also more toxic than dust or granules.

TIMING AND FREQUENCY IN EFFICIENT USE OF INSECTICIDE

P. Kenmore and O. Mochida

The insecticide-induced resurgence of BPH reported in Mindanao (Peralta et a1 IRRN, April 1983) is the the first confirmed case of resurgence and hopperburn on certified IR36 in Philippine farmers' fields.

The degree of resurgence, indicated by BPH density at 77 days after transplanting (DT), was determined by the frequency of applications and their timing. Plots treated at 42 and 49 DT had more BPH than the other treated plots. During the 7th week after transplanting, light trap catches of BPH were four times higher than their previous peak and remained high for 3 weeks. This heavy catch might have been due to the maturing of surrounding farmers' fields and suggested BPH immigration. Even the fields where insecticides had been applied had signifcantly high BPH densities during that period.

The results showed the critical importance of good monitoring of pest populations and field evaluation of insecticides in relation to natural pest population dynamics (not just pest pressure). Timing should mean biological timing. Threshold-based application was introduced in Philippine farmers' IPC classes as a new method of timing to be used with previous recommendations.

In Indonesia, differences were reported in yield response to frequency of insecticide applications depending on the season. In the 1976 dry season, more than two applications and even as many as 12 applications of carbofuran and diazinon did not significantly increase yields. In the next wet season, yield increased with corresponding applications up to the sixth application, then leveled off.

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STATISTICAL PROBLEMS FOR LABORATORY AND FIELD TESTS

K. A. Gomez

Statistical procedure should fit the specific problems and needs of a given experiment. It should not be applied ritualistically. Entomologists and statisticians working together must consider the following problems unique to entomological trials to achieve the most appropriate statistical procedure.

When grain yield data must be collected along with data on insect incidence, two sources of variation, soil heterogeneity and nonuniform insect distribution, must be handled simultaneously. In addition, unlike soil heterogeneity, which can be effectively handled by proper blocking, insect direction and distribution are unpredictable.

The primary types of data collected in an entomological trial are percentage and count data, neither of which can be expected to follow the normal distribution. Thus, appropriate modifications of standard statistical procedures, such as data transformation (arc sine or logarithmic) and probit analysis, are generally needed for application to percentage and count data.

Most insecticide treatments produce large border effects, and generally require the use of plot sizes that are much larger than those normally required for accurate yield determination.

In a field trial, if the level of insect infestation is not high enough for a valid evaluation of insect control methods, the resulting data would not be meaningful and should be discarded.

With the increased importance of IPM, the use of factorial experiments — rather than the traditional single-factor experiments, is expected to increase. Experimental designs suitable for factorial experiments, such as split-plot designs, should be considered.

DISCUSSION

KENMORE: What do you think of nonpredictability of insect influxes if the Latin square design is used?

GOMEZ: Although the Latin square design is able to handle two sources of variation, the variations must be predictable because blocking is done before the start of the experiment.

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Also, because of its requirement that the number of replications must equal the number of treatments, the Latin square design is rarely used in field trials.

ISHIKURA (comment): Hopper concentration in fields is often unpredictable. This may create difficulties in designing experiments. In laying out the experimental plots in a field, the heterogenous distribution of insect populations must be considered. Stem borer population is generally high in the center of the field, but stink bug and other species, which have breeding sites on the bank and other places, have highest populations in the perimeter.

APPENDIX

SAMPLING AND MONITORING TECHNIQUES FOR FLOODED RICE: IRRI'S CURRENT APPROACH

T. J. Perfect

A dynamic approach to pest management presupposes the ability to:

1) define the pest problem, quantitatively and qualitatively;
2) interpret observed infestation levels in terms of potential yield loss;
3) select the appropriate course of remedial action;
4) assess the impact of any control measures applied; and
5) refine and improve the decision-making process in the light of experience.

Nutrient disorders are frequently mistaken for and treated as insect problems by farmers.

Correct identification and reliable quantitative estimates are essential for valid decision-making. IRRI has conducted many sampling trials in flooded rice using a wide variety of methods. The sampling method must be carefully selected in relation to the type of information required. Sampling may be broadly categorized as research-oriented and management-oriented.

Research-oriented sampling. Research-oriented sampling strongly emphasizes efficiency and precision. It is used to quantify the insect-host plant interactions that would serve as a basis for understanding the damage relationships and lead to the development of economic thresholds. It is used in studies of population dynamics.

Data on leafhoppers, planthoppers, and natural enemies for research purposes are collected primarily with suction samplers, the D-Vac and FARMCOP. These samplers have been evaluated for efficiency and precision (Perfect, T. J., A. G. Cook, and E. R. Ferrer. 1983. *Bull. Ent. Res.* 73:345–355).

Management-oriented sampling. Management-oriented sampling uses simple, low cost, low-technology methods sufficiently reliable for realistic decision-making.

Well-understood techniques, once available, can be used to calibrate other simpler methods for use in management programs. Visual counts and the use of a sticky paddle were compared with absolute estimates obtained by combined D-Vac + FARMCOP sampling. The results are encouraging. With established and calibrated appropriate techniques, they must be assimilated into a system of monitoring. A methodology for this is being developed and tested at IRRI.

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Two kinds of information are being collected:

1. The relationship of seasonal periodicity and abundance, with observed infestations on the farm, using traditional trapping techniques such as light, pan, and suction traps.
2. Direct crop monitoring, further subdivided into:
   a) Farm surveys designed to provide semiquantitative information and locate potential problem areas.
   b) Action-oriented monitoring to provide information on which to base control decisions.

   Frequently thresholds for action in researchers' plots differ from those that would be adopted in production systems because of the experimental nature of the trials. For some of these, the tolerance threshold to damage is very low and economics are a secondary consideration, though the same sampling principles operate.

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