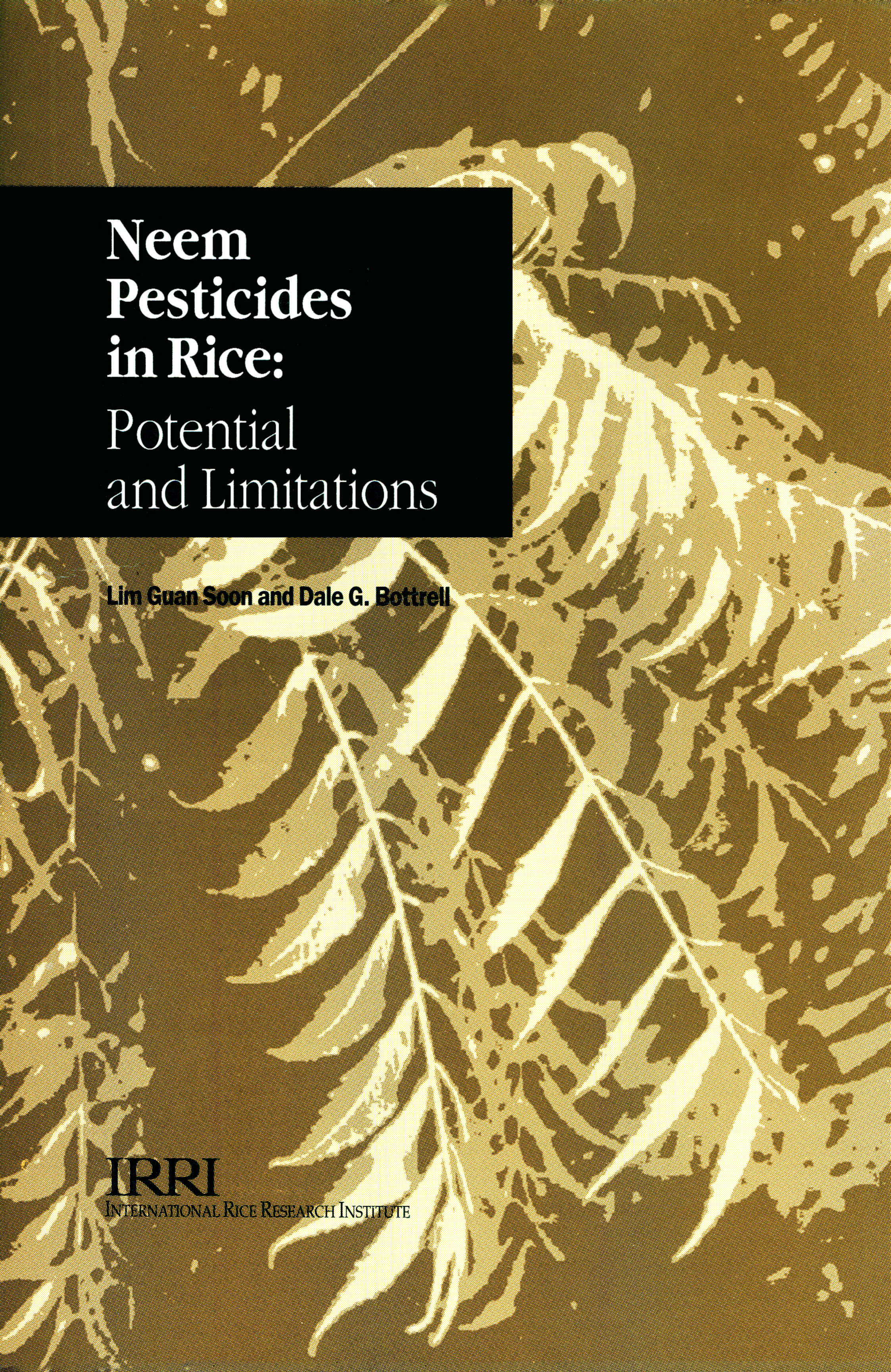

Neem Pesticides in Rice: Potential and Limitations

Lim Guan Soon and Dale G. Bottrell

IRRI
International Rice Research Institute

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The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of 18 nonprofit International research centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization of the United Nations (FAO), the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). Its membership comprises donor countries, international and regional organizations, and private foundations.

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The responsibility for this publication rests with the International Rice Research Institute.

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Foreword

The International Rice Research Institute (IRRI) started research on botanical pest control in rice and rice-based cropping systems in the late 1970s. Focusing mostly on neem tree (*Azadirachta indica*) products, the research involved close cooperation with national institutions in many Asian countries and the International Centre of Insect Physiology and Ecology. Special project support was provided by the Asian Development Bank (ADB) and Swiss Cooperation Development.

IRRI's mandate is to improve the well-being of present and future generations of rice farmers and consumers, particularly those with low incomes. In line with this mandate, we fully support the concepts and practices of integrated pest management (IPM). IRRI considers IPM to be an important component of efforts to achieve and sustain profitable and stable rice production. Ample numbers of case history studies and large-scale pilot operations show convincingly that IPM can reduce unnecessary pesticide use, stabilize crop yields, increase farmer profits, and restore ecological balance.

This publication reviews the status and prospects of pest control using neem in rice-based cropping systems in developing countries, with special emphasis on its potential and limitations in IPM programs. The ultimate value of any control method in IPM is how much the method contributes to increased farmer profit and sustained crop production, and protects health and the environment. Another requirement is the reliability of the method in achieving acceptable pest control.

To some, neem and other botanical pest control products are the ideal arsenal against pests because they are naturally occurring and are renewable — appealing features in a world of diminishing natural resources. However, just because they are natural botanical products is no guarantee that they are always safe to the environment and nontarget organisms. Results reported in this publication show that neem adversely affects some nontarget organisms but does not affect others. With today's concerns about the effects of agricultural development on biodiversity, we especially need to be alert for potentially harmful effects of pest control products on nontarget organisms. I am pleased that IRRI has placed considerable emphasis on this aspect of research.

Acknowledgments

This publication marks the climax of IRRI's involvement in botanical pest control. Those who contributed to the work include:

Ramesh C. Saxena, who started research on neem at IRRI and who pioneered much of the work on botanical pest control in rice in Asia.

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- South China Agricultural University, Guangzhou, Guangdong, China
- Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India
- University of the Philippines, Los Baños, Laguna, Philippines

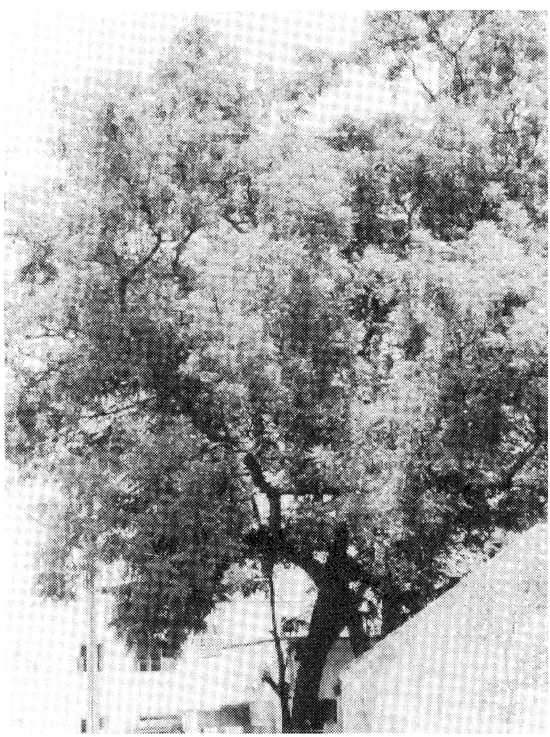
Abbreviations and acronyms

ai	= active ingredient
ADB	= Asian Development Bank
AZT-VR-K	= neem-enriched formulation of neem seed kernel extract
Bt	= *Bacillus thuringiensis*
EC	= emulsifiable concentrate
EPA	= Environmental Protection Agency
G	= granule
HCN	= hydrocyanic acid
IPM	= Integrated Pest Management
IRRI	= International Rice Research Institute
LC_{50}	= lethal concentration (50%); the concentration of a pest control agent (expressed in ppm, etc.) required to kill 50% of a test population
LD_{50}	= lethal dose (50%); the dose (expressed in mg pesticide per kg. etc. of test organism) to kill 50% of a test population
PhilRice	= Philippine Rice Research Institute
TNAU	= Tamil Nadu Agricultural University
ULV	= ultralow volume
WP	= wettable powder

Chapter 1

Introduction

Effective crop protection is an integral component of efforts to increase and sustain rice *Oryza sativa* yields. Chemical control using synthetic pesticides dominates crop protection methods in many areas planted to high-yielding rice. However, concerns for economic. environmental, and social issues challenge their continued use. The past 10 yr have produced considerable evidence that questions whether routine chemical treatment for insect control is necessary to protect the yields. For example, a survey in



1. The neem tree, commonly grown near Indian homes.

irrigated rice in Central Luzon, Philippines (Teng 1990), found that untreated rice yielded the same amount as rice treated 1-5 times with insecticides. Yet 97% of irrigated rice farmers in this area routinely apply chemicals.

Many pesticides used are ecologically disruptive, adversely affect the environment, and can seriously harm farmers' health. Poor farmer health has a negative impact on rural productivity (Marquez et al 1992, Pingali 1992).

Many national and international organizations and farmer groups are reevaluating the need for continued heavy use of insecticides and are promoting integrated pest management (IPM). IPM uses pest-resistant varieties and biological and cultural methods to control pests, resorting to pesticides only when other methods fail to reduce theireffects. Pesticides are used only after critical assessment shows that their benefits outweigh the economic, environmental, and social costs.

Table 1. Crops associated with rice in multiple cropping systems in Asia (Teng 1990).

Cropping pattern[a]	Rice ecosystem[b]				
	Irrigated	Rainfed	Upland	Deepwater	Tidal
Rice	+	+	+	+	+
Rice - wheat	+	+	+	+	-
Rce - barley	+	+	+	-	-
Rice - maize	+	+	+	-	+
Rice - millet	-	+	-	-	-
Rice - rice	+	+	+	+	-
Rice - mungbean	-	+	+	-	-
Rice - chickpea	-	+	-	+	-
Rice - cowpea	+	+	-	-	+
Rice - black gram	-	+	-	+	-
Rice - lentil	-	+	-	+	-
Rice - peanut	-	+	-	-	-
Rice - mustard	+	+	-	+	-
Rice - sunflower	-	+	-	-	-
Rice - sesame	-	+	-	+	-
Rice - soybean	+	-	-	-	-
Rice - jute	-	+	-	+	-
Rice - potato	+	-	+	+	-
Rice - vegetables	+	-	+	+	+
Rice - rice - rice	+	-	-	-	-
Rice - rice - chickpea	-	+	-	-	-
Rice - rice - barley	-	+	-	-	-
Rice - maize - peanut	-	+	-	-	-
Rice - rice -wheat	+	-	-	-	-
Rice - maize - maize	-	-	+	-	+

[a]Rice *Oryza sativa,* wheat *Triticum aestivum,* barley *Hordeum vulgare,* maize *Zea mays,* millet *Coix lachryma-jobi,* mungbean *Phaseolus mungo,chickpea Cicer arietinum,* cowpea *Vigna unguiculata,* black gram *Vigna mungo,* lentil *Lens culinaris,* peanut *Arachis hypogaea,* mustard *Brassica juncea,* sunflower *Helianthus annuus,* sesame *Sesamum indicum,* soybean *Glycine* max, jute *Corchorus olitorius,* and potato *Solanum tuberosum.* [b]+ = rice and other crop(s) are grown in association in a particular rice ecosystem, – = there is no association.

IPM can provide enormous benefits to rice farmers. For example. in Bangladesh, farmers practicing IPM achieved 13.5% higher rice yields and reduced pesticide expenditure by 75% (Kenmore 1991); Indonesia has saved US$100-150 million per yr in foreign currency by eliminating pesticide subsidies and promoting IPM in rice as an alternative (Indonesian National IPM Program 1991 ; Oka 1989, 1991).

In recent years scientific research organizations and chemical companies have become increasingly interested in using products derived from the neem tree *Azadirachta indica* (Fig. 1) for controlling rice pests. Neem has been used for pest control since ancient times. Recent scientific and commercial interest in neem has evolved in response to the need to find alternatives to costly and hazardous synthetic pesticides.

The status and prospects of using neem in pest control of rice in developing countries, with special emphasis on its potential and limitations in IPM programs, is reviewed here. Because rice is frequently grown in multiple cropping systems (Table 1), neem use in some crops with which rice is associated is also reviewed.

Chapter 2

Traditional and modern perspectives of neem

Traditional use

Use of natural products to protect crops from pests traces back to early recorded history. Rice farmers in Southeast Asia used concoctions of inorganic and organic materials to control pests long before synthetic pesticides were introduced (Maata 1987). They derived many of these materials from plants. Some traditional botanical pest control methods are still used, especially by rice farmers not yet heavily influenced by modern technology.

Traditional botanical pest control methods mostly treated the pests' habitats with leaves, stems, seeds, roots, or other plant structures known to kill or repel the pests (Golob and Webley 1980). Sometimes the plant materials were chopped or ground into powders or liquids.

Neem *A. indica* (= *Antelaea azadirachta, Melia azadirachta*) is a member of the mahogany family (Meliaceae). Originally from South and Southeast Asia, it was one of the earliest used botanical pest control agents (Ahmed and Koppel 1987, BAIF 1988, Golob and Webley 1980). Today, the tree grows in Asia, Africa, the Americas, Australia, and other areas with a tropical or subtropical climate. In recent years, neem (also called Margosa tree and Indian lilac) has attracted interest because of its pesticidal products, its fuelwood and shade value, and as a component of reforestation. The fast-growing plant may reach a height of 25 m. The oval fruits (1.4-2.4 cm long) are produced in drooping panicles usually once and sometimes twice a year. They are the principal sources for pesticidal chemicals, but the leaves also are commonly used for these chemicals (Schmutterer 1990b).

An age-old practice in India is to mix neem leaves with stored rice grains or to crush neem fruits on storage facility walls to prevent insect damage (Pruthi and Singh 1944). Farmers have traditionally ground neem leaves, soaked them overnight in water, and treated the planted rice crop with the extract (IRRI 1989, 1991).

One feature of neem is that it can be grown by the user. Rural Nepalese, for example, commonly plant neem trees near their homes to harvest for pest control products (Pradhan 1991).

Recent trends

Since the 1960s, efforts to modernize and intensify rice production in tropical Asia have displaced many traditional practices. Fanners became used to applying synthetic insecticides to the new high-yielding rice varieties at fixed, preventive intervals even when the rice was free of harmful insects. Insecticide use spiraled as high-yielding varieties displaced traditional varieties and in many areas synthetic pesticides became the predominant method of rice pest control. Initially these were used to control insect pests andeventually weeds and some diseases. Worldwide, rice now accounts for more pesticides than any other crop, with a global value, in 1988, of US$2.4 billion (Woodburn 1990). More than 90% of chemical pesticides are applied to Asian riceland. Japan, the Republic of Korea, and China are the primary consumers (Table 2). Fungicides are mostly used in temperate rice-growing areas. Insecticides are the most commonly used pesticides in tropical Asia, but rice farmers increasingly use herbicides to replace hand labor and to control weeds in seeded rice where hand weeding is impractical. These pesticides—and especially insecticides—have created some problems.

Many insecticides used on rice crops are in the World Health Organization's extremely hazardous categories I and II. Philippine studies show that unsafe application techniques and use of category I and II insecticides greatly harm health and reduce the productivity of rice farmers in the Philippines (Pingali and Marquez 1990).

Insecticides also affect the environment. Lim and Ong (1987) reported that ricefield fish declined substantially in areas where certain insecticides were applied to rice. Cagauan (1990) found that all insecticides used in Philippine ricefields were toxic to fish. Other adverse environmental impacts in the aquatic rice environment have been documented (Pingali 1992). Pesticide residues were detected in snails, fish, and frogs (Ocampo et al 1991) in treated rice and in nearby well water (Medina et al 1991).

Insecticides may be especially harmful to natural enemies—beneficial predators and parasitoids—important in controlling insect pests. Serious outbreaks of brown

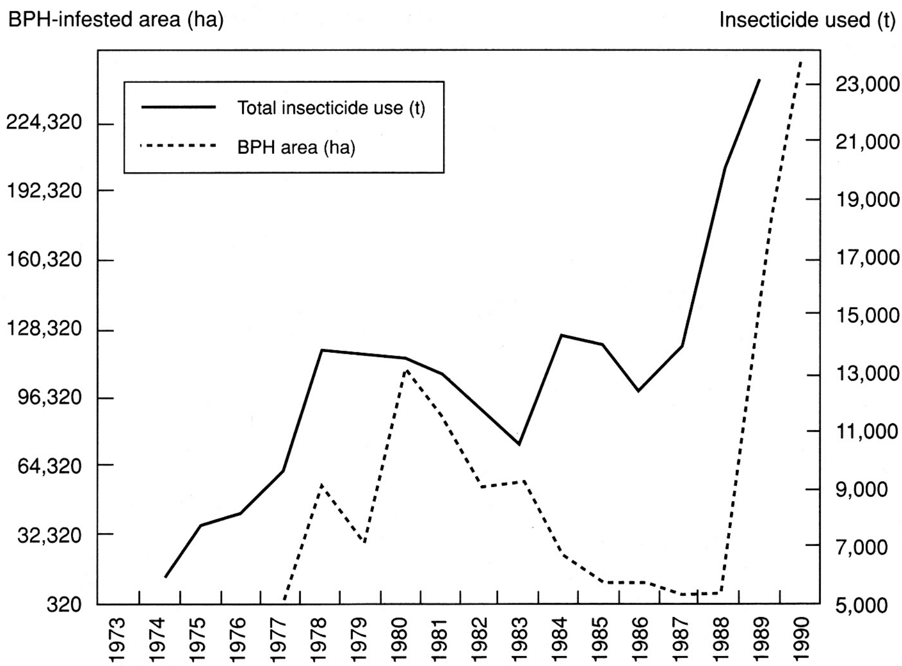
Table 2. Rice pesticide market values (US$ million), by country, 1988.[a]

Country	Herbicides	Insecticides	Fungicides	Others	Total
Bangladesh	3	14	7	0	24
Brazil	46	1	3	0	50
China	11	108	35	0	154
Europe	48	24	5	0	77
India	18	51	14	2	85
Indonesia	4	24	1	2	31
Japan	570	455	375	20	1420
Myanmar	2	8	4	0	14
Pakistan	1	3	0	0	4
Philippines	17	28	0	3	48
South Korea	48	89	95	3	235
Taiwan	26	38	18	5	87
Thailand	17	21	1	0	39
USA	61	22	4	0	87
Vietnam	2	9	2	0	13
Rest of the world	11	15	6	0	32
Total	885	910	570	35	2400

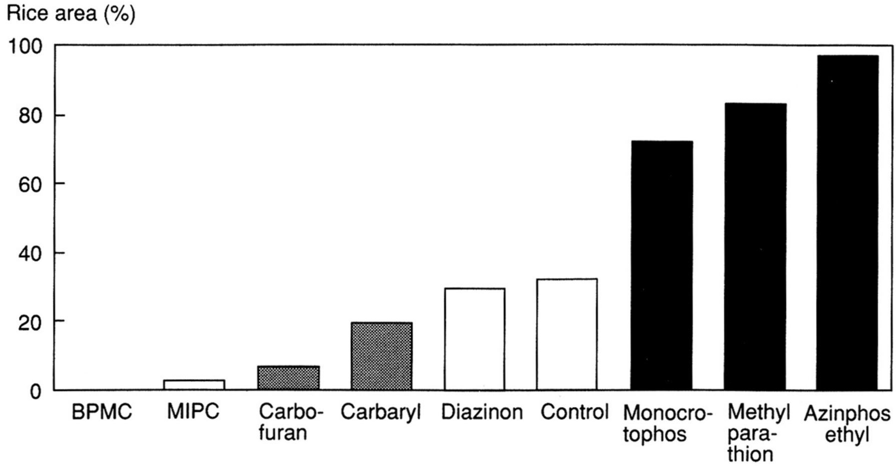
[a]Based on estimates by Allan Woodburn Associates Ltd. and Landell Mills Market Research Ltd. (Woodburn 1990).

planthopper *Nilaparvata lugens* have occurred in numerous rice areas in Asia treated heavily with insecticides. The insecticides destroyed the brown planthopper's natural enemies, but not the pest's eggs (Kenmore 1980, 1991; Ooi 1988). Planthopper numbers may simply increase as increasing volumes of insecticides are sprayed. Fields suffering from hopperburn may be completely destroyed. Thailand, for example, has had two major brown planthopper outbreaks in the past 15 yr. Both outbreaks (late 1970s-early 1980s and 1989-90) were preceded by major increases in insecticide use (Fig. 2). Many commonly used rice insecticides cause brown planthopper outbreaks (Fig. 3).

Compounding the problem, some insect pests have evolved genetic strains that tolerate insecticides. Resistance usually develops most quickly under the selective pressure of repeated insecticide applications. Surviving members of one generation pass the resistance character to the next generation. Eventually, if every generation is exposed to an insecticide that selects for resistance, the population may contain largely resistant individuals. Brown planthoppers have developed moderate to high levels of resistance to a range of insecticides. The problem has been most serious in Taiwan, China (Sun et al 1984), Japan (Ozaki and Kassai 1982), and the Republic of Korea (Park and Choi 1991). The effectiveness of an insecticide is completely lost when high levels of resistance develop.



2. Relationship of insecticide use and brown planthopper (BPH) infestations in Thailand, 1973-1990 (Kenmore 1991).



3. Percent of rice area showing hopperburn 13 wk after transplanting following treatment with foliar sprays at 4,7, and 10 wk after transplanting (Kenmore 1991).

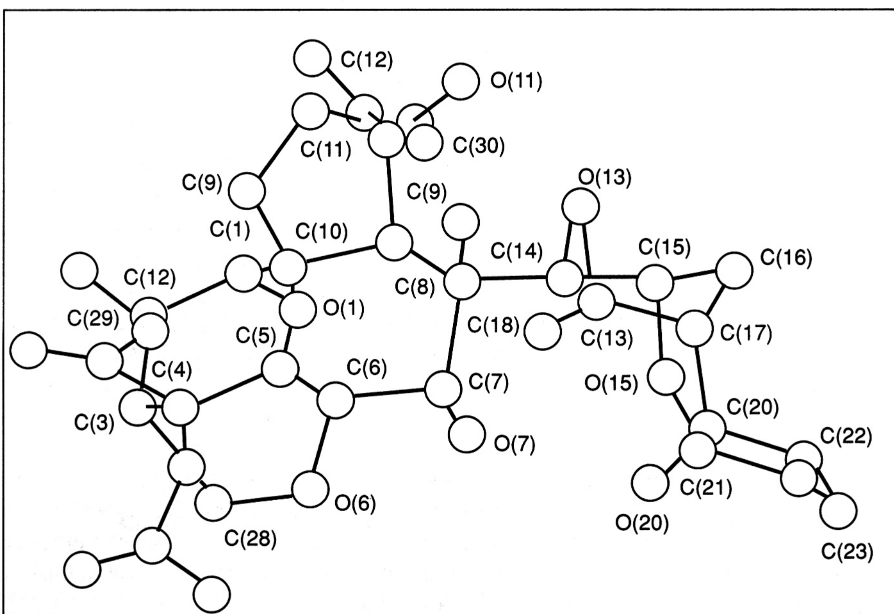
A major reason for the recent interest in neem is the widely held view that neem is safe to humans, the environment, and natural enemies of pests, and some researchers (e.g., Saxena 1989) believe that insect resistance to neem products is unlikely. Chapter 4 reviews the effects of neem on nontarget organisms, and Chapter 8 examines the likelihood of insect resistance to neem products.

Chapter 3

Using neem to control pests

Neem products have been used to control a wide range of insect pests and plant disease organisms. Traditional methods, as discussed in Chapter 2, mostly used whole plants or plant parts with minimal modification. Many of these traditional methods are still used in some areas. Modern methods for using neem products include the application of low-volume or ultralow-volume (ULV) sprays; powders; seed and seedling treatments; and soil amendments (Table 3) (Abdul Kareem et al 1988, IRRI 1989, Jacobson 1990, Schmutterer 1990b, Schmutterer and Ascher 1987).

Azadirachtin, a steroid-like tetranortriterpenoid (limonoid), is considered the most active pesticidal compound of neem (Fig. 4). All parts of the neem tree contain



4. Azadirachtin, the most active pesticidal compound of the neem tree.

Table 3. Formulations and techniques for preparing neem pesticides.

Formulation or technique	Effectiveness	Reference
Sprays		
Low volume	3% neem oil and 5% neem seed kernel extract effectively controlled white stem borer *Scirpophaga innotata* in Indonesia	Soejitno (1992)
Ultralow volume	Ultralow volume application of 50% neem oil: custard apple *Annona squamosa* oil mixture (4:1) significantly reduced green leafhopper *Nephotettix virescens* populations and whiteheads caused by yellow stem borer *Scirpophaga incertulas;* no effect on brown planthopper	Abdul Kareem et al (1988)
Electrodyn	Electrodyn formulation of neem oil applied against Malayan black bug *Scotinophara coarctata* infestation in farmers' fields reduced the pest population significantly and increased yield	Abdul Kareem et al (1988)
Powders	2.5 parts of powdered neem kernels to 100 parts of cowpea *Vigna unguiculata* seeds in storage effective against common stored product insects for 8-12 mo	Ivbijaro (1983)
Seedling root dips	Rice seedlings root-dipped in 5% neem seed kernel extract for 12 h reduced egg laying and hatching of green leafhopper *Nephotettix virescens*	Abdul Kareem et al (1988)
Neem cake soil amendment	Neem cake applied at 1,800 kg/ha highly effective in controlling root-knot nematode *Meloidogyne javanica* that attacks okra *Abelmoschus esculentus* and tomato *Lycopersicon esculentum*	Singh and Sitaramaiah (1966)

azadirachtin, but it is more concentrated in the seed. The content of azadirachtin per neem tree varies greatly between locations, and other factors may also contribute to variability (Table 4). Neem also has other compounds with pesticidal properties (Schmutterer 1990b), but most research has focused on azadirachtin which is the most used ingredient in commercial products.

Neem's pesticidal action is not understood for all pests. The compound azadirachtin may work as an insect growth regulator interfering with ecdysone (the key insect molting hormone), which prevents immature insects from molting. Neem products may also repel insects, stop their feeding, inhibit reproduction, and cause other interruptions (Schmutterer 1990b).

One constraint to the use of neem is its slow-killing (knock down) effect on some insect pests compared with most synthetic insecticides. The speed of action varies according to the insect pest species, its life stage, and environmental factors (temperature, etc.). The slow-killing effect may contribute to a farmer's perception that neem is not very effective (Librero et al 1988, IRRI 1989).

The most commonly used application methods for rice and other crops in rice-based multiple cropping systems include spraying, soil amendments, and protecting

Table 4. Variability of azadirachtin content in neem seeds cultivated in different areas (Benge 1986, Jacobson 1986).

Location	Azadirachtin content [a]
Caribbean	Generally very low (lowest amount = 0.05 mg/g)
Africa	Generally high (up to 6.2 mg/g)
India	Several sources (less than 0.2 mg/g)

[a] May be influenced by factors such as genetic variation, age of tree, time of picking seeds, and seed handling (e.g., cleaning, drying, storing, and shipping).

the harvested products in storage. Neem products may be used alone, mixed with other botanical products (e.g., oil of custard apple), or mixed with synthetic pesticides.

Crop sprays

The traditional way to prepare neem spray is by soaking chopped or ground leaves in water for several hours and then straining off the residues. The water-neem extract mixture is sprayed on crops (IRRI 1989, 1991). Sprays are also made from crushed neem seeds or seed kernels that have been soaked in water (NRC 1992).

A more modern method is to use oil sprays (IRRI 1989). Neem seed oil is prepared by drying, decorticating, and grinding seeds, then steaming or mixing with boiling water (Benge 1986). The oil that separates out is sprayed on crops.

Various commercial formulations of neem pesticides are now available (Table 5). However, there are no data to determine the quantity being used.

Table 5. Examples of neem products commercially available for pest control.

Product	For use on plant	Effective against	Reference
Biosol	Rice	Rice leaffolder *Cnaphalocrocis medinalis*	IRRI (1989)
Margoside CK (20 EC)	Rice	Whitebacked planthopper *Sogatella furcifera*	Shukla et al (1991)
Margoside OK (80 EC)	Rice	Whitebacked planthopper	Shukla et al (1991)
Margosan-O	Potato	Colorado potato beetle *Leptinotarsa decemlineata*	Zehnder and Warthen (1990)
Neemark	Rice	Whitebacked planthopper	Shukla et al (1991)
Neemin	Rice	Whitebacked planthopper	Shukla et al (1991)
Repelin RD9	Broccoli	Diamondback moth *Plutella xylostella*	Abdul Kareem et al (1988)
	Rice	Brown planthopper *Nilaparvata lugens*	IRRI (1989)
	Rice	Whitebacked planthopper	Shukla et al (1991)
		Stem nematode *Ditylenchus angustus*	IRRI (1991)
	Tomato	Root-knot nematode *Meloidogyne* spp.	IRRI (1989)
Welgro	Broccoli	Diamondback moth	Abdul Kareem et al (1988)
	Rice	Whitebacked planthopper	Shukla et al (1991)
	Tobacco	Tobacco mosaic virus	IRRI (1989)
	Tomato	Root-knot nematode	IRRI (1989)

Soil amendments

In India, many farmers routinely incorporate neem cake into the soil of their rice fields. Reportedly, the soil amendment has value as fertilizer and as a systemic pesticide. The cake, which is the fruit-seed residue after neem oil is extracted, is incorporated into the soil as basal fertilizer. The soil treatment protects young rice from insect pests, especially green leafhoppers *Nephotettix* spp., and the tungro virus that they transmit (Abdul Kareem et al 1988), and suppresses sheath rot fungus *Sarocladium oryzae,* and kills or repels soil-infesting nematodes, such as *Ditylenchus angustus* (IRRI 1991).

Jayaraj (1991) reported that soil amendments are also effective in other crops. For example, a postpruning topdress of neem cake (1-2 kg/vine) to grapes *Vitis* sp. suppressed the root-knot nematode *Meloidogyne incognita.*

Postharvest protectants

Neem derivatives are often used to protect harvested grains kept in bags and stores in India (Ketkar 1987). Successful control of a range of stored grain insect pest species has been reported (Golob and Webley 1980; Schmutterer and Ascher 1984, 1987; Schmutterer et al 1982).

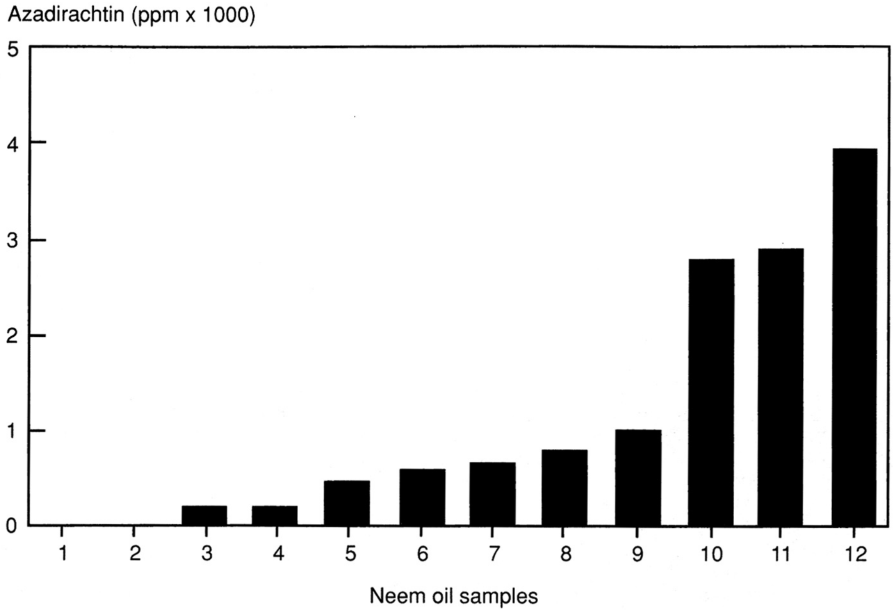
In warehouses, 1-2% powdered neem seed kernel mixed with harvested rice significantly reduced insect pest infestations (Ketkar 1976). Mixing neem leaves with harvested rice, treating storage bags with 2% neem extract, or putting dried neem leaves (20-30 cm thick) between the bags and storage floor achieved similar results (Muda 1984). Wheat stored in jute bags treated with 5% aqueous neem seed extract or 20% extract of neem leaves was protected from insect damage for up to 6 mo (Jilani and Amir 1987). In Sind, Pakistan, treated jute bags resulted in cost-benefit ratios (cost benefits per monetary unit invested) of 4.6, 5.6, and 7.4, for small-, medium-, and large-scale farmers (Jilani and Amir 1987).

For postharvest protection, farmers frequently mix harvested grains with neem leaves, stems, seeds, or roots that have been chopped or ground into powder (Golob and Webley 1980).

Inconsistency of field applications

Results of many field trials show that neem products suppress a wide range of pests (Isman et al 1990). However, results at a given location are often inconsistent between years, and at different locations results may be conflicting. Differences in product quality, formulation, application technique, and perhaps environmental factors contribute to these inconsistencies. Azadirachtin concentration may differ significantly among neem oil samples (Fig. 5). Isman et al (1990) found that of 12 neem oil samples, 2 completely lacked detectable amounts of azadirachtin (detection limit about 50 ppm). The remaining 10 samples ranged from about 200 to 4,000 ppm (0.02-0.4%). In another study, the authors detected one neem oil sample that contained about 6,800 ppm azadirachtin.

Field evaluations of neem oil applied to rice provide conflicting results. For example, the oil was not effective against brown planthopper and whitebacked planthopper *Sogatella furcifera* in Hangzhou, China, (Table 6); green leafhopper



5. Azadirachtin content of 12 neem oil samples as determined by high pressure liquid chromatography (Isman et al 1990).

Table 6. Field efficacy of neem oil against rice brown planthopper and whitebacked planthopper in Hangzhou, China, 1990 (China National Rice Research Institute, unpubl. data).

Treatment	Corrected mortality[a] (%)	
	Whitebacked planthopper	Brown planthopper
3% neem oil (2.5 liter/ha)	36.8	23.2
3% neem oil (5.0 liter/ha)	19.2	8.6
3% neem oil (1.5 liter/ha) + JGMS[c] (2.5 liter/ha)	11.4	[b]
3% neem oil (2.5 liter/ha) + 25% buprofezin (Applaud WP) (0.15 kg/ha)		29.3
5% Repelin (2.5 liter/ha)	13.5	–22.7
25% buprofezin (Applaud WP) (0.3 kg/ha)	89.0	56.2

[a]Corrected against the untreated control. [b]Data not available. A local plant product in China

N. virescens in Thailand (Jahn 1992); or tungro in Nueva Ecija, Philippines (Table 7, Estoy et al 1992). However, workers in other areas of China (Chiu et al 1992), Philippines (Abdul Kareem et al 1988), and India (Jayaraj 1988, Narasimhan and Mariappan 1988) reported satisfactory results with neem oil applications to rice. Yet in Bangladesh, Rezaul Karim (1991) obtained conflicting results from repeated field trials using neem oil on rice.

Table 7. Efficacy of neem products against the rice green leafhopper *N. virescens* and rice tungro virus in Nueva Ecija, Philippines, 1991 (Estoy et al 1992).

Treatment[a]	Days after transplanting[b,c]				
	14		49		77
	Green leafhopper	Tungro	Green leafhopper	Tungro	Tungro
5% neem seed kernel extract	18.0 b	0	30 a	42.8 bc	87.6 a
3% neem oil	16.0 b	0	30 a	37.2 b	81.3 a
Carbofuran + cypermethrin + benomyl	6.0 a	0	27 a	18.5 a	78.1 a
Untreated	11.8 ab	0	34 a	46.0 c	92.0 a

[a] For neem seed kernel extract and neem oil treatments, neem cake (150 kg/ha) was applied as basal. Carbofuran (Furadan 3G) (1.05 g ai/ha) was applied to nurseries 10 d after sowing. Cypermethrin (Cymbush 5 EC) (178.12 g ai/ha) was applied as spray at 15, 24, and 35 d after transplanting. Benomyl (Benlate 50 WP) (100 g ai/ha) was applied at 25 and 40 d after transplanting. [b] Number of green leafhoppers/10 net sweeps and tungro-infected hills/plot; av of 5 replications. In a column, means sharing a common letter are not significantly different at the 5% level. [c] High tungro incidence caused heavy crop loss, preventing harvest for yield data.

Inconsistent results with neem products show the importance of repeating field trials for several crop cycles and at different locations, and of using uniform procedures in experimental design, data collection, and analysis. Analysis should compare control efficacy, costs, benefits, and net profits of neem with those of synthetic pesticides normally used on the crop.

Neem products, especially oil formulations, may be toxic to rice (see Chapter 8). This can be a serious limitation and must be examined carefully before neem products are recommended to farmers.

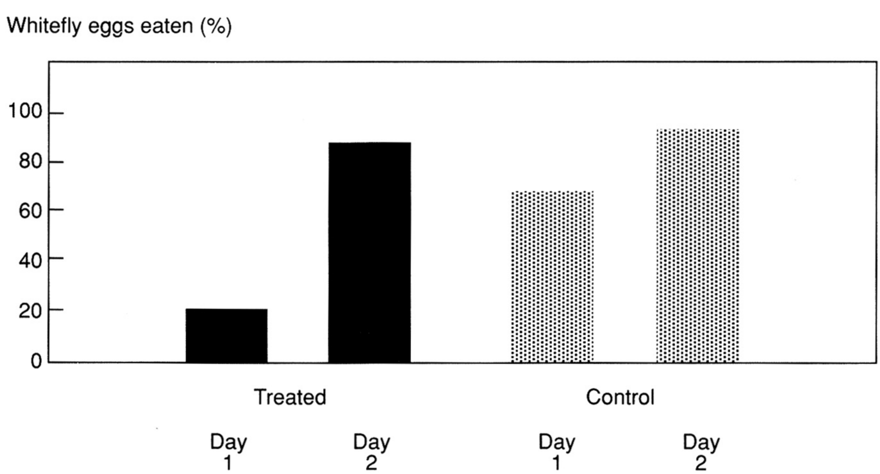
Chapter 4

Effects of neem on nontarget organisms

Many people assume that because botanical pesticides are natural products, they are safe to humans and other nontarget organisms. Most available literature on neem only discusses the effects on target pests. This chapter reviews some of the known effects of neem on nontarget organisms.

Effects on natural enemies

Studies on neem's impact on natural enemies (i.e., beneficial predators and parasitoids that attack pests) have documented effects ranging from harmless to adverse (Table 8). Reports of adverse effects on natural enemies have included reduced emergence of adult parasitoids from neem-treated parasitoid cocoons. e.g., braconid wasp *Cotesia plutellae* (Loke et al 1990); direct mortality, e.g., green mirid bug *Cyrtorhinus lividipennis* (Saxena et al 1984); repellency, e.g., coccinellid beetle *Delphastus pusillus* (Hoelmer et al 1990); and reduced fecundity, e.g., bethylid wasp *Goniozus triangulifer* (*Lamb* and Saxena 1988). Although neem adversely affected some natural



6. Effects of neem (Margosan-O) treatment on feeding of the predator *Delphastus pusillus* on whitefly *Bemisia tabaci* eggs (Hoelmer et al 1990).

Table 8. Effects of neem products on natural enemies of insect pests of rice and other crops.

Natural enemy	Test plant (and conditions)	Effects	Reference
Neem oil			
Mirid predator *Cyrtorhinus lividipennis*	Rice (lab)	Moderately toxic at and above 10 µg/female	Saxena et al (1984)
Wolf spider *Pardosa pseudoannulata*	Rice (lab)	None	Saxena et al (1984)
Black cricket predator *Metioche vittaticollis*	Rice (lab)	Predation of leaffolder *Marasmia patnalis* eggs decreased	Lamb and Saxena (1988)
Black cricket predator *M. vittaticollis,* ground beetle predator *Ophionea nigrofasciata,* and lady beetle predator *Micraspis* sp.	Rice (field)	Populations unaffected	Lamb and Saxena (1988)
Sword-tail cricket predator *Anaxipha longipennis*	Rice (field)	Predator numbers reduced	Lamb and Saxena (1988)
Predatory coccinellids	Sorghum (lab)	Predators survived; target aphid *Melanaphis sacchari* successfully controlled	Srivastava and Parmar (1985)
Braconid parasitoid *Cotesia plutellae*	Mustard (lab)	Reduced adult emergence from cocoons treated at concentrations higher than 2.5%; longevity also reduced	Loke et al (1990)
Neem seed kernel extract			
Wolf spider *P. pseudoannulata*	Rice (lab)	None	Saxena et al (1984)
Clubionid spider *Chiracanthium mildei*	Bean leaf disc (lab)	None	Mansour et al (1987)
Predatory phytoseid mite *Phytoseiulus persimilis*	Bean leaf disc lab)	Predator less affected than its prey, the carmine spider mite *Tetranychus cinnabarinus*	Mansour et al (1987)
Scelionid parasitoid *Telenomus remus*	Tobacco (lab)	Oviposition on treated egg masses of common cutworm *Spodoptera litura* unaffected; emergence normal but longevity reduced when treated before oviposition; longevity increased if applied after egg deposition	Joshi et al (1982)

Table 8 continued

Natural enemy	Test plant (and conditions)	Effects	Reference
Neem seed bitters			
Black cricket *M. vittaticollis* and meadow grasshopper *Conocephalus longipennis* predators	Rice (field)	Populations unaffected	Lamb and Saxena (1988)
Coccinellid predator *Micraspis* sp.			
Carabid predator *Ophionea nigrofasciata*			
Black cricket predator *M. vittaticollis*	Rice (lab)	Predation on leaffolder *M. patnalis* eggs unaffected	Lamb and Saxena (1988)
Bethylid parasitoid *Goniozus triangulifer*	Rice (lab)	Lethal concentration of 50 µg/female: emergence of parasitoids from treated leaffolder *M. patnalis* hosts and parasitoid fecundity reduced: treated hosts less preferred than untreated hosts	Lamb and Saxena (1988)
Eulophid parasitoid *Tetrastichus howardi* (synonyms. *T. ayyari* and *T. israeli*)	Rice (lab)	Emergence decreased in parasitized pupae exposed to 1,000 ppm	Lamb and Saxena (1988)
Margosan-0			
Braconid parasitoid *Lysiphlebus testaceipes*	Hibiscus (lab)	Adult emergence from treated parasitized (mummified) aphids *Aphis gossypii* unaffected	Hoelmer et al (1990)
Aphelinid parasitoid *Eretmocerus californicus*	Hibiscus (lab)	Parasitoid emergence from parasitized (mummified) sweet potato whitefly *Bemisia tabaci* less than half of untreated; untreated whiteflies attacked at a rate three times more	Hoelmer et al (1990)
Coccinellid predator *Delphastus pusillus*	Hibiscus (lab)	Preferred untreated eggs of sweet potato whitefly when given a choice of treated and untreated; no difference in preference on	Hoelmer et al (1990)

enemies, its impact was short-lasting. For example, the coccinellid predator *D. pusillus* avoided the eggs of its treated prey (whitetly *Bemisia tabaci*) for 1 d, then resumed feeding the next day (Hoelmer et al 1990) (Fig. 6). Neem had a longer lasting impact on other natural enemies, for example, the larval parasitoid G. *triangulifer* of the rice leaffolder *Marasmia patnalis* (Table 8; Lamb and Saxena 1988), when emergence of adult parasitoids from neem-treated pupae and fecundity of the emerging adults were lowered.

In 1991, IRRI and collaborators of the IRRI-ADB botanical pest control project (IRRI 1991, 1992; Appendix 2) took steps to expand knowledge on the effects of neem on natural enemies. Effects were measured in controlled laboratory and field experiments using similar procedures at all locations. Natural enemies included major arthropod predators and parasitoids inhabiting rice and rice-based crops in South and

Table 9. Effects of neem products on natural enemies, IRRI-ADB botanical pest control project (IRRI 1991, 1992). [a]

Product	Natural enemy	Effect	Institution[b]
Neem oil 50% EC	Green lacewing *Chrysopa carnea*	No mortality up to 20 ml/liter of water (recommended field rate of 3 ml/liter)	TNAU
	Eulophid wasp *Tetrastichus howardi* (synonyms, *T. ayyari* and *T. israeli)*	No mortality up to 6 ml/liter of water	TNAU
	Black mirid bug *Tytthus parviceps*	LC_{50} = 2.876% compared with LC_{50} = 8.407% for malathion (Malathion 57 EC); neem oil relatively safer to black mirid bug than to its brown planthopper prey	DRR
	Eulophid wasp *T. howardi*	Inhibited parasitoid emergence from striped stem borer pupae treated with 3% concentration; as toxic to parasitoid as 0.41% chlorpyrifos (Brodan 31.5 EC) Insecticide	IRRI
3% neem oil	*T. howardi*	Nearly as toxic as 0.41% chlorpyrifos (Brodan 31.5 EC)	IRRI
	Scelionid wasp *Telenomus rowani*	Adult parasitoid emergence and longevity reduced	IRRI
5% neem seed kernel extract	*T. howardi*	Parasitoid emergence unaffected when host pupae treated; sex ratio altered from 1 male: 1.5 females to 1 male: 5 females; fecundity of emerging females unaffected	IRRI

[a]The project's official name was Technical Assistance for Strengthening of Rice Crop Protection Research and Minimizing Environmental Damage in Developing Member Countries, Phase II (Asian Development Bank Technical Assistance #5349). [b]DRR = Directorate of Rice Research, Hyderabad: IRRI = International Rice Research Institute, Los Baños; and TNAU =Tamil Nadu Agricultural University, Coimbatore. See Appendix 3 for other collaborating institutions.

Southeast Asia. This was the first coordinated effort involving several institutions to determine neem's impact on these organisms. Collaborating institutions also studied neem's effects on various nontarget organisms other than natural enemies (Appendix 3).

Table 9 summarizes some of the results of the effects of neem products on natural enemies obtained by IRRI-ADB project investigators. Neem oil (50% EC) had no effect on the predatory green lacewing *Chrysopa carnea* or the eulophid parasitoid *Tetrastichus howardi* (synonyms, *T. ayyari* and *T. israeli*), but was more toxic (LC_{50} = 2.876%) than malathion (Malathion 57 EC) (LC_{50} = 8.407%) to the predatory black mirid *Tytthus parviceps.* Further, it was nearly as toxic as the insecticide chlorpyrifos (Brodan 31.5 EC) to *T. howardi.* Neem oil reduced the emergence and longevity of the scelionid parasitoid *Telenomus rowani.* Neem seed kernel extract (5%) altered the sex ratio of *T. howardi* adults that emerged from treated pupae of the striped stem borer *Chilo suppressalis.*

Effects on honey bees

Neem's effects on honey bees *Apis mellifera* and other pollinators have received little attention. Margosan-O was not toxic to worker honey bees in the United States when applied at doses of up to 4,4 18 ppm azadirachtin/ha. In a German study, three sprayings of a neem-enriched formulation of neem seed kernel extract (coded as AZT-VR-K) (500 ppm/liter of water) to tansy phacelia *Phacelia tanacetifolia* and other plants in full bloom had no negative effects on a queen and about 3,000 worker bees in a screenhouse. Some damage was observed in two much smaller colonies consisting of a queen and about 200-300 workers, where a number of young bees were unable to emerge from the cells (Schmutterer and Holst 1987).

Effects on earthworms

Treatment of soil with either ground neem leaves or ground neem seed kernels (each treatment consisted of 5% volume of the treated soil), slowed entry of the earthworm *Eisenia foetida,* indicating a short-term repellency effect. However, the earthworm population in neem-treated soil (both treatments) gained significantly more weight after 4 wk than the control population in nontreated soil. Also, survival and fecundity of earthworms in the neem-treated soil were significantly higher (Rossner and Zebitz 1987).

Effects on fish and other aquatic organisms

Little is known about the effects of neem products on nontarget aquatic organisms in tropical rice environments. Most information on the effects on aquatic organisms is from temperate environments of developed countries where the aquatic flora and fauna are quite different. An acute toxicity (LD_{50}) of Margosan-O occurred in rainbow trout *Salmo gairdneri* within 96 h in 8.8 ml/liter of water and in bluegill sunfish *Lepomis macrochirus* within 96 h in 37 ml/liter of water (Table 10) (Larson 1987). Young guppies *Lebistes reticulatus* tolerated 100 ppm AZT-VR-K/liter of water (Zebitz 1987), and Schmutterer (1990b) concluded that Margosan-O toxicity to fish is

Table 10. Toxicological tests with Margosan-O in the United States (Larson 1987).

Test organism	Results
Water flea *Daphnia magna*	48 h LC_{50} = 13 mg/liter of water 48 h no observed effect < 10 mg/liter of water
Mallard duck *Anas platyrhynchos*	No negative effects in feeding studies
Bluegill sunfish *Lepomis macrochirus*	96 h LC_{50} = 37 ml/liter of water 96 h no observed effect = 20 mg/liter of water
Rainbow trout *Salmo gairdneri*	96 h LC_{50} = 8.8 ml/liter of water 96 h no observed effect = 5.0 mg/liter of water
Guinea pig *Cavia porcellus*	No positive reaction in sensitization study
Bobwhite quail *Colinus virginianus*	Acute oral LC_{50} > 7,000 ppm
Rabbit *Oryctolagus cuniculus*	Acute dermal LC_{50} > 2.0 ml/kg Low-moderate primary irritation to shaved skin Minimal eye irritation
Rat *Rattus* sp.	Acute oral LC_{50} = 5.0 ml/kg Acute inhalation LC_{50} > 43.9 mg/liter per h In immune response studies, electrophoretic pattern showed difference in globulin fractions; significant change in poly-morphonuclear count; overall, no adverse immune response

probably caused by its petroleum oil content (15%) or another compound used for its formulation.

Margosan-O is also toxic to the water flea *Daphnia magna* (Table 10) and other invertebrates that inhabit stagnant water (Larson 1987). Aqueous neem seed kernel extract has been reported to kill the ostracod *Heterocypris luzonesis,* which feeds on nitrogen-fixing blue-green algae (Grant and Schmutterer 1987). The Margosan-O label states "Do not apply directly to water or wetlands" because of the toxicity problem to aquatic invertebrates. Margosan-O is manufactured by W.R. Grace & Co. in the United States.

The IRRI-ADB project (IRRI 1991,1992) measured the effects of neem on several common aquatic species inhabiting tropical Asian ricefields (Appendix 3). Studies in the Philippines showed that the recommended dose (5%) of neem seed kernel extract was toxic to Nile tilapia *Oreochromis niloticus,* but neem oil (50% EC at 3 ml/liter) did not appear to harm the fish (Fernandez et al 1992). In laboratory assays, the LC_{50} of neem oil for carp *Cyprinus carpio* was 302.7 ppm at 24 h after treatment (Fernandez et al 1992). Studies in India found that no Java tilapia *Oreochromis mossambicus* died when exposed at and below 0.01 % neem seed kernel extract or neem oil (50% EC) (Jayaraj 1992). Neem seed kernel extract and neem oil were not toxic to the common ricefield toad *Bufo* sp. when used below 0.1% concentration (Jayaraj 1992).

Effects on humans and other warm-blooded animals

For centuries neem products have been used for health applications such as antiviral and antifungal treatments and dental hygiene. Millions of people in Asia and Africa brush their teeth and gums with a neem twig (Alam 1991, NRC 1992). Tests in Germany have shown that neem extracts prevent tooth decay (NRC 1992).

Extracts from neem are used in toothpaste, body soap, skin ointment, and other body preparations (Fig. 7, NRC 1992).

The traditional Hindu empirical Ayurvedic medicine uses neem seed extracts (including neem oil), neem leaf extracts, and extracts from neem bark and roots (Schmutterer 1990b). This system of medicine, practiced in India for about 2,000 yr, uses combinations of herbs, purgatives, rubbing oil, and other concoctions to prevent and cure human illness.

In the United States, Margosan-O underwent comprehensive toxicological tests prior to the Environmental Protection Agency's (EPA) registration of the compound for commercial use on nonfood crops. Table 10 shows some of these findings. Tests for skin irritation, eye irritation, inhalation, mutagenicity, and immune response were low enough to allow EPA registration (Larson 1987, Schmutterer 1990b).

However, neem oil reportedly caused the death of children in India when used to cure minor ailments (Sundaravalli et al 1952). In Malaysia, children who ingested unrefined neem oil acquired a Reye-like syndrome, a severe disorder that involves swelling of the brain, liver, and other organs (Sinniah and Baskaran 1981). In South India where neem oil is widely used, epidemiological studies revealed numerous deaths caused by ingesting the oil (Sinniah et al 1981). These poisonings apparently resulted because the neem seeds from which the oil was extracted had been contaminated with aflatoxin-producing strains of the fungus *Aspergillus flavus* (Sinniah et al 1983). When extracted from clean and fungus-free seed kernels, neem oil did not cause any oral toxicity in laboratory rats even at 5,000 mg/kg body weight (NRC 1992).

Neem products appear to present feu hazards to humans. if free of contaminants and used properly. However, like any pesticide, they need to be handled cautiously. Neem products have been used for many years and are well entrenched in various cultural practices, but this does not necessarily mean that they are always safe.

7. Neem toothpaste (left) and neem medicine (right) are common consumer products in India.

Neem products appear to present few hazards to other warm-blooded animals. A formulation of AZT-VR-K at a dose of 5,000 mg/kg body weight caused no acute oral toxicity to rats or dermal toxicity to rabbits (Schmutterer 1984). Methanolic neem seed kernel extract at 5,000 and 8,750 mg/kg body weight and neem oil at a concentration of 5,000 mgkg body weight caused no acute oral toxicity to rats (Schmutterer 1984, 1990b). Further, subacute injections with an aqueous neem seed kernel extract (25 and 50 g kernel/liter) caused no toxicity, and when 50 g kernel/liter was applied, no eye irritation or dermal toxicity resulted (Schmutterer 1990b). Similar results were obtained with Margosan-O (Table 10).

Some birds and bats eat the pulp of neem fruits without apparent harmful effects, and in areas such as Ghana's Accra Plains, neem fruits are a main source of their diet (NRC 1992).

Need for better understanding of nontarget effects

The assumption that botanical materials are less toxic than synthetic pesticides to humans and other nontarget species has been a primary driving force behind the recent promotion of neem-based pest control. This review shows that neem products are generally safer than comparable synthetic pesticides. However, it is also clear that neem products may harm some beneficial natural enemies and aquatic species associated with rice culture. With today's concerns about agricultural effects on biodiversity, neem researchers need to be particularly alert for potentially harmful effects. Long-term effects of neem on aquatic organisms and the behavior and fitness of natural enemies need special investigation. Neem should not be recommended for pest control in a given area until scientific data show that it will provide economically beneficial and environmentally sound long-term results.

Chapter 5

Socioeconomics of neem

Understanding the social and economic factors that affect human behavior helps to explain how and why farmers and policymakers choose to adopt certain pest control technologies. Especially in India, socioeconomic studies have provided useful insights into farmer use, farmer perception, the economic benefits, and commercial influence of neem.

Use patterns

Surveys in India show that farmers use neem and other botanical pest control products on many crops (Table 11). Neem is the predominant botanical species used and neem cake the most commonly used product.

Table 11. Surveys on production, trade, and use of neem and other botanical pest control products in India (IRRI 1989).

Survey	Findings
145 farmers (1986)	48% used synthetic pesticides, 38% used pesticide/botanical pesticide combinations, and 5% used only botanical pesticides
	Used neem cake (250-625 kg/ha) as soil amendment to control nematodes in cardamom and insects in rice
	Used botanical pesticides against storage pests
19 villages in Pune Ahmednagar (1987)	Farmers commonly used neem cake to control pests of potato, tomato. peanut (groundnut), and grapes
	They believed neem cake supplied nutrients, minimized nitrogen losses, reduced pests, and improved quality of farm produce
900 farmers in 9 states (1988)	80% of cardamom growers and many citrus, sugarcane, and vegetable growers Incorporated neem cake into the soil at 100-1,000 kg/ha to protect against soil-borne pests, including nematodes
	Neem cake was considered to have "fertilizing value"

Table 11 continued

Survey	Findings
	Most users of neem were commercial farmers and considered "progressive" by other farmers Few rice growers used neem cake as "organic manure" Many in Tamil Nadu applied neem cake mixed with urea to prevent early pest attack Majority of resource-limited farmers mixed neem leaves obtained from nearby trees with harvested wheat, rice, maize, sorghum, and pulses stored for more than 3 mo Some also used leaves of karanja *Pongamia pinnata* (=*glabra*) and Indian privet *Vitex negundo,* either alone or with neem In eastern Andhra Pradesh, 30% of tobacco nursery growers frequently used neem seed kernel extract sprays to control tobacco diseases Some prepared neem seed kernel extract themselves and others purchased it from neighbors or traders Common commercial products were Repelin (against brown planthopper and white-backed planthopper on rice) and Welgro (against diseases in tobacco nursery) 50,000 liters of Repelin and 70,000 t of Welgro were sold in eastern Andhra Pradesh in 1988-89

Raveendaran and Kandaswamy (1988a) surveyed 300 farmers in the Periyar, Salem, and Thanjavur districts of Tamil Nadu in 1987-88 to determine farmers' use of botanical insecticides. All farmers surveyed practiced some form of chemical control. In Thanjavur, 84% of the farmers were aware of botanical insecticides, and 8 1 % used neem products; in Salem 77 and 66%; and in Periyar 52 and 42% were aware of and used neem products (Table 12). Neem products were used prophylactically in combination with synthetic insecticides. The study showed that farmers using neem produced no more than farmers using only synthetic insecticides (Table 13).

Neem is frequently promoted as a pesticide technology ideally suited for use by farmers with small holdings and limited resources. However, Palanisami (1992) found that in Tamil Nadu, farmers with larger holdings actually used more neem per ha than the farmers with smaller holdings (Table 14). This study also showed that farmers with larger holdings used more non-neem crop protection chemicals.

Costs and benefits

Only rarely have neem products been evaluated in terms of the relative costs of the level of control achieved and the costs of the products plus application costs. Abdul Kareem et al (1988) provided one of the few evaluations when they compared a neem "package"

Table 12. Awareness and use of botanical insecticides among 300 farmers in 3 districts Of Tamil Nadu, India (Raveendaran and Kandaswamy 1988a).

	District		
	Thanjavur	Salem	Periyar
Farmers (%)			
Aware of botanical Insecticides	84	77	52
Using botanical insecticides	81	66	42
Crop area (ha)			
Using neem oil	62	8	-[a]
Using neem cake	68	70	30
Using both neem oil and neem cake	37	-	-
Total area in survey	167	78	30

[a]Data not available.

Table 13. Crop productivity with and without neem products in 3 districts of Tamil Nadu, India, based on a survey of 300 farmers (Raveendaran and Kandaswamy 1988a).

District and crop	Crop productivity (kg/ha) when using			
	Neem oil + synthetic[a]	Neem cake + synthetic[a]	Neem oil and neem cake + synthetic[a]	Only synthetic insecticides
Thanjavur				
Rice	4,162	4,179	4,248	4.229
Salem				
Rice	4,246	4,439	-[b]	4.414
Sugarcane	-	87,608	-	95.359
Turmeric	-	4,513	-	4.468
Cotton	1,623	1,524	-	1,588
Periyar				
Rice	-	5,177	-	5.031
Sugarcane	-	105,479	-	104.979
Turmeric	-	5,459	-	5.528

[a]Farmers combined neem with different synthetic insecticides in various proportions. [b]Data not available.

treatment with an insecticide treatment of monocrotophos (Azodrin 202 R) to reduce leaffolders (species name not provided) and tungro virus. In one trial, they found that the neem package was more cost-effective than monocrotophos (Table 15). However, in another similar trial the neem package failed to show any cost advantage.

Results from field trials in rice generally show that neem products provide satisfactory and consistent results only if used in combination with synthetic insecticides. Used alone, their impact on yield varies widely. Usually neem-treated plots yield only marginally better than untreated plots (Table 16; Abdul Kareem et al 1988).

K. Palanisami (Tamil Nadu Agricultural University, India, 1992, unpubl. data) compared the economics of pest control on farms using and not using neem in Tamil Nadu. Farmers using neem always used the material in combination with other crop protection chemicals. Their rice yields were 7.5% more (but not statistically significant at the 5% level) than rice yields of farmers not using neem. Rice farmers using neem

Table 14. Farmer use of neem products and other plant protection chemicals in Tamil Nadu, India, by size of farm holding (K. Palanisami, TNAU, Coimbatore, India, unpubl. data). [a]

Farm holding (ha)	Neem products			Other crop protection chemlcals (liter/ha)
	Dust (kg/ha)	Cake (kg/ha)	Oil (liter/ha)	
>2	18.7	91.6	1.9	5.1
1-2	12.4	60.4	1.0	3.7
<1	14.1	51.4	0.8	3.9

[a] Based on a survey of 300 farmers (149 with >2 ha, 111 with 12 ha, and 40 with <1 ha).

Table 15. Comparison of a neem package and insecticide monocrotophos (Azodrin 202 R) applied to IR36 to control rice tungro virus and leaffolders (Abdul Kareem et al 1988).

	Tungro-Infected hills/plot [a] (no.) Days after transplanting			Leaffolder larvae/ 15 hills [b] (no.)	Yield		Treat-ment cost (US$)	Net gain (US$)
	25	45	65		Amount (t/ha)	Value (US$)		
Neem package[c]	4 a	83 b	153 b	35 b	3.1 a	517	6	511
Monocrotophos (Azodrin 202 R) [d]	4 a	44 c	106 b	29 b	3.5 a	583	177	406
Untreated control	5 a	138 a	307 a	49 a	2.5 b	417	– [e]	–

[a] In a column, means followed by the same letter are not significantly different at the 5% level. [b] In a column, means followed by the same letter are not significantly different at the 10% level. [c] Seed treatment, seedling root dip, and foliar spraying with neem. [d] Applied as foliar spray. [e] Data not available.

Table 16. Effect of neem and insecticide treatments on tungro virus and IR36 yield (Abdul Kareem et al 1988).

Treatment	Tungro-Infected hllls/plot [a,b] (no.)	Yield[b] (t/ha)
Neem oil + neem cake (4 liter/ha)	181 bc	3.6 b
Neem oil (2 liter) + monocrotophos (Azodrin 202 R) (0.38 liter ai/ha)	75 a	4.2 a
Monocrotophos (Azodrin 202 R) (0.38 liter ai/ha)	59 a	4.3 a
Monocrotophos (Azodrin 202 R) (0.75 liter ai/ha)	90 ab	4.1 a
Untreated control	236 c	3.4 b

[a] At 65 d after transplantlng. [b] In a column, means followed by the same letter are not significantly different at the 1% level.

also made 7.7% more profit per ha (but not significantly more at the 5% level) than other farmers. However, yields for other crops when using neem (always in combination with other crop protection chemicals) were less: for cotton *Gossypium hirsutum* by 7.9%, maize *Zea mays* by 5.5%, and cholam *Sorghum bicolor* by 15.7% (but not significantly less at the 5% level). Likewise, farmer profits for those using neem were 18.8% less for cotton, 25.2% less for maize, and 22.6% less for cholam (but not significantly less at the 5% level) than farmers not using neem. Analysis did not separate the effects of neem from those of other crop protection chemicals, for all farmers used neem in combination with other crop protection chemicals.

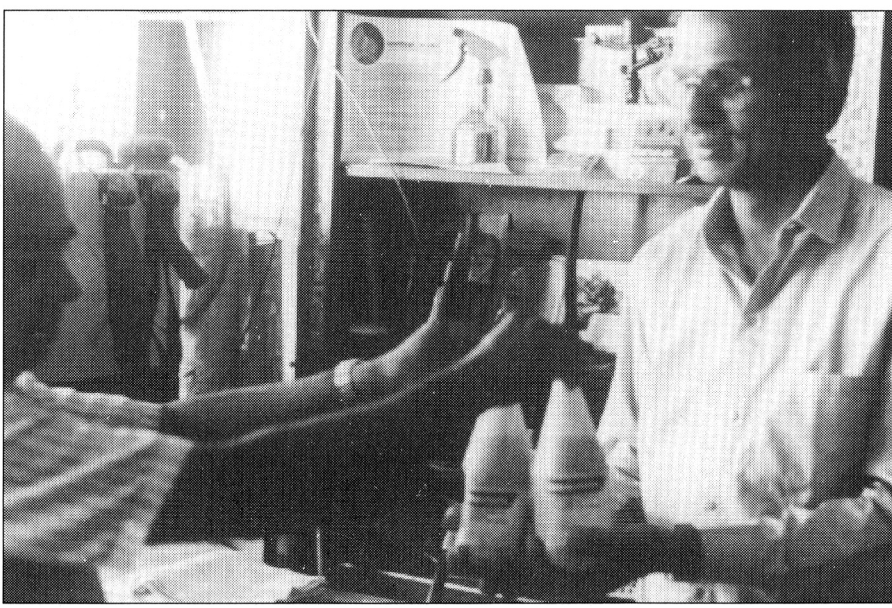
The commercial neem industry

Commercialization of neem products (Fig. 8) is expanding. A 1985-87 survey of 48 neem oil-producing units in Maharashtra and Tamil Nadu, India, showed an 80% increase in trade of neem seeds. These commercial seed-crushing operations manufactured neem pesticides and other neem products. About 70% of them used either rotary or expeller crushers, and individual firms crushed from 20 to 25,000 t of seeds annually. The remaining firms extracted oils using solvents. On average, the processing units recovered 15% neem oil and 77% neem cake from the processed seeds. About 8% was wastage and moisture loss (IRRI 1989).

Traders usually purchased depulped and dried seeds from farmers and village merchants and sold them to wholesalers or to neem oil-producing units. Smaller traders bought and sold within a 10-km radius while larger traders extended beyond 300 km (IRRI 1989).

From 1985 to 1987, the total neem seed sold by 11 traders in Tamil Nadu increased from 679 to 1,239 t. The quantity sold per dealer ranged from 2.5 to 450 t. Average purchase price increased from US$0.11 to 0.12/kg and the selling price from US$0.15 to 0.18/kg (IRRI 1989).

Total fixed and variable costs were US$180/t of the neem seed crushed. Average income for the seed crushers was US$200 when the selling price per kg was USS1.13



8. Selling commercial neem pesticides in India.

Table 17. Costs and returns (US$/t) in neem seed processing in Tamil Nadu, India (Raveendaran and Kandaswamy 1988b).

Cost item	Rotary		Expeller	
	Amount	% of total	Amount	% of total
Variable cost				
Seeds (1,000 kg)	146.67	81.35	146.67	82.32
Brokerage and commission	1.47	0.82	1.47	0.83
Sales tax	2.20	1.22	2.20	1.23
Loading, transport, and unloading	8.00	4.44	8.00	4.49
Storage	2.07	1.15	2.07	1.16
Drying charge	1.21	0.67	1.21	0.67
Milling (decortication) and drying kernels	1.11	0.62	1.11	0.62
Labor for crushing	1.22	0.67	0.50	0.28
Molasses for rotary	0.62	0.34	–[a]	–
Fuel or expeller boiling unit	–	–	0.50	0.28
Powdering oil cake	0.32	0.18	0.32	0.18
Electricity	1.33	0.74	0.83	0.47
Machinery repair	0.26	0.12	0.50	0.28
Interest (14% for 6 mo)	11.65	6.46	11.57	6.50
Total variable cost	178.13	98.80	176.95	99.31
Fixed cost				
12% interest on fixed capital (1 yr for rotary unit and 6 mo for expeller unit; expeller crushes 1,000 t in 6 mo)	1.53	0.85	0.87	0.49
Depreciation	0.63	0.35	0.36	0.20
Total	180.29	100.00	178.18	100.00
Receipts from				
Sale of 139.50 kg neem oil (US$1.13/kg)	158.10			
Sale of 241.83 kg of neem cake (US$0.1066/kg)	25.80			
Sale of 557.78 kg of seed outer coat . (US$0.0267/kg)	14.87			
Total receipts	198.77			
Net income (US$/t)				
Rotary	18.48			
Expeller	20.59			

[a]Data not available.

for neem oil, US$0.10 for neem cake, and US$0.03 for neem seed kernel. The minimum initial capital investment was US$l0,000 (IRRI 1989).

Raveendaran and Kandaswamy (1988b) studied the earnings of 30 neem oil mills in Coimbatore, Periyar, Salem, and Kamarajar in 1987-88. Of neem seed crushed, millers netted US$18.48 in rotary units and 20.59/t in expeller units (Table 17). Returns per dollar in rotary units were US$0.l0 for total investment and US$0.116 for operational cost. Returns per dollar in expeller units were US$0.12 for total investment and US$0.123 for operational cost. Millers considered these good profits (Raveendaran and Kandaswamy 1988b).

In a 1991 survey in Tamil Nadu, Palanisami (1992) found the total capital investment for rotary oil mills to be US$11,059 and for expeller mills US$13,020 per mill. Per ton of processed neem seeds, millers incurred total processing costs of US$154.24 in rotary mills and US$153.61 in expeller mills, and earned a net return of US$16.67 in rotary mills and US$21.29 in expeller mills.

Prices of neem fruit and seed, neem oil, and neem cake have been rising steadily over the last decade in India (Ketkar 1988). Table 18 shows production and sale of neem oil and neem cake from 1977-78 to 1987-88.

Benge (1986) computed the yearly gross income per ha to demonstrate the potential profitability of producers growing neem for azadirachtin harvest (Table 19). He used the following low-high range of variables: number of trees per ha, 225-400; azadirachtin content, 2-9%; fruit yield per tree, 25-50 kg: and wholesale price of azadirachtin per kg, US$80-160. He assumed that the trees would begin producing harvestable products after 5 yr and reach full production in 10 yr. Yield was estimated at 25 kg/tree at year 5, increasing to 50 kg/tree at year 10.

Producing neem trees for azadirachtin may not be as economically viable as Benge (1986) had computed. Studies of 30 trees aged 8-30 yr in the States of Gujarat, Karnataka, Maharashtra, and Tamil Nadu showed that neem trees produced only 12-30% of the amount Benge projected (IRRI 1989). Fruit yield was only 3-15 kg/tree (IRRI 1989) compared with 25-50 kg/tree that Benge (1986) had projected. Although the average per tree yield (14.01 kg) obtained by Bharatiya Ago-Industries Foundation (Table 20: BAIF 1988) was higher than the per tree yield reported by IRRI (1989), it was still significantly less than the amounts Benge (1986) had calculated.

Potential for a cottage industry

While farmers may produce neem for use against pests, surveys conducted by Palanisami (1992, unpubl. data) showed that farmers in India usually buy neem pesticidal products manufactured by local commercial companies. He also found that

Table 18. Neem fruit collection, production, and sale of neem oil and neem cake by Gramodyog Non-Edible Oil and Soap Producers Cooperation Society Ltd., Sumerpur (Rayasthan) (Ketkar 1988).

Year	Neem fruit collection (t)	Production (t)		Sale (t)	
		Neem oil	Neem cake	Neem oil	Neem cake
1977-78	204,967	10,480	159,409	11,540	184,123
1978-79	135,440	6,635	95,857	6,654	110,490
1979-80	114,459	7,113	92,796	7,667	196,810
1980-81	105,022	9,152	85,688	9,290	90,345
1981-82	168,460	9,904	116,104	9,915	116,959
1982-83	598,711	26,453	329,419	23,369	352,500
1983-84	125,878	16,200	239,678	17,886	235,805
1984-85	533,567	28,828	380,243	17,375	356,115
1985-86	569,918	21,355	390,411	35,522	378,730
1986-87	338,315	19,152	306,365	22,706	300,171
1987-88	840,020	36,816	521,116	37,483	519,363
Av	339,523	17,463	247,008	18,128	258,310

Table 19. Estimated potential yearly gross income (US$) of producers selling neem fruits for azadirachtin production (Benge 1986).

Azadirachtin content (%) x kg fruits/tree x US$/kg price for fruits	Trees/ha (no.)	
	225	400
0.02 x 25 x 80	9,000	16,020
0.09 x 25 x 80	40,500	72,090
0.02 x 50 x 80	18,000	32,040
0.09 x 50 x 80	81,000	144,180
0.02 x 25 x 160	18,000	32,040
0.09 x 25 x 160	81,000	144,180
0.02 x 50 x 160	36,000	64,080
0.09 x 50 x 160	162,000	288,360

Table 20. Fresh fruit yield of neem trees of different ages in 3 states of India (BAIF 1988).

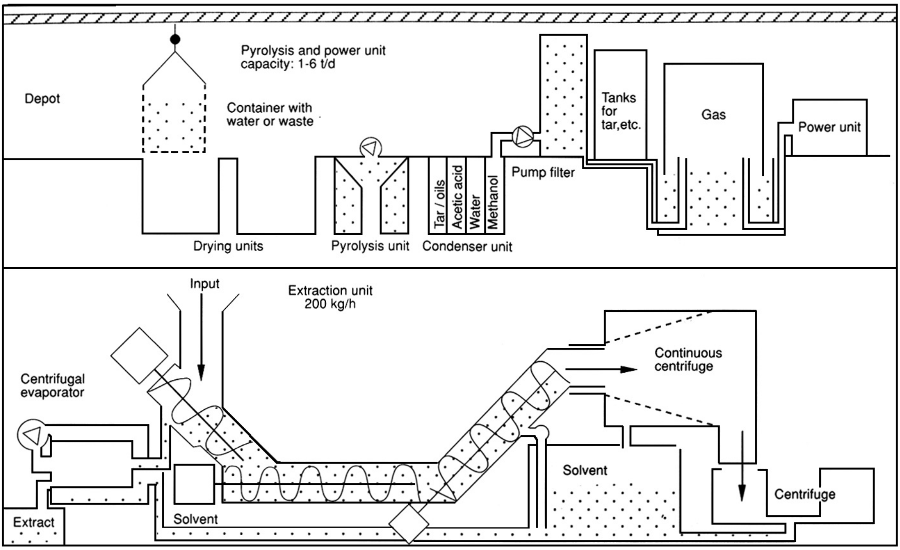
Age (yr)	Yield per tree (kg)			
	Maharashtra	Gujarat	Karnataka	Av
8-10	8.06	10.03	9.00	9.03
15-20	11.07	16.00	12.00	13.02
> 20	17.05	20.03	21.75	19.61
Av	12.06	15.35	14.25	13.89

farmers frequently have difficulty finding these products in local markets. Improved local production units, which must be simple and must incorporate inexpensive equipment and chemicals, would probably make neem pest control attractive to more farmers (Sharma 1984). A small-scale cottage industry system (Fig. 9), as proposed by Michel-Kim and Brandt (1982), would have a capacity of processing 1-10 t of neem daily. Figure 10 shows the potential outputs from this system in addition to pest control products.

Constraints

Neem-based pest control technology is constrained by a number of technical and socioeconomic factors (Table 21). These constraints exist even in areas of India where neem-based pest control has been used traditionally. One important constraint is that farmers have insufficient data on product effectiveness under farm conditions to convince them of the benefits. Another is that the raw products are cumbersome to handle, making them less attractive than the more easily dispensed synthetic pesticides. The quality of raw botanical materials may vary greatly and may not be reliable (see Chapter 3). In addition, extension workers often do not have information to provide guidelines on correct use and timing.

Comprehensive economic analyses are needed (both at the farm- and macro-levels) so that governments and other institutions can formulate policies on neem use. The analyses should consider national needs, governmental support policy, and marketing structure (Radwanski 1982).



9. A proposed pyrolysis and power unit (top) and an extraction unit (bottom) of a neem processing plant (Michel-Kim and Brandt 1982).

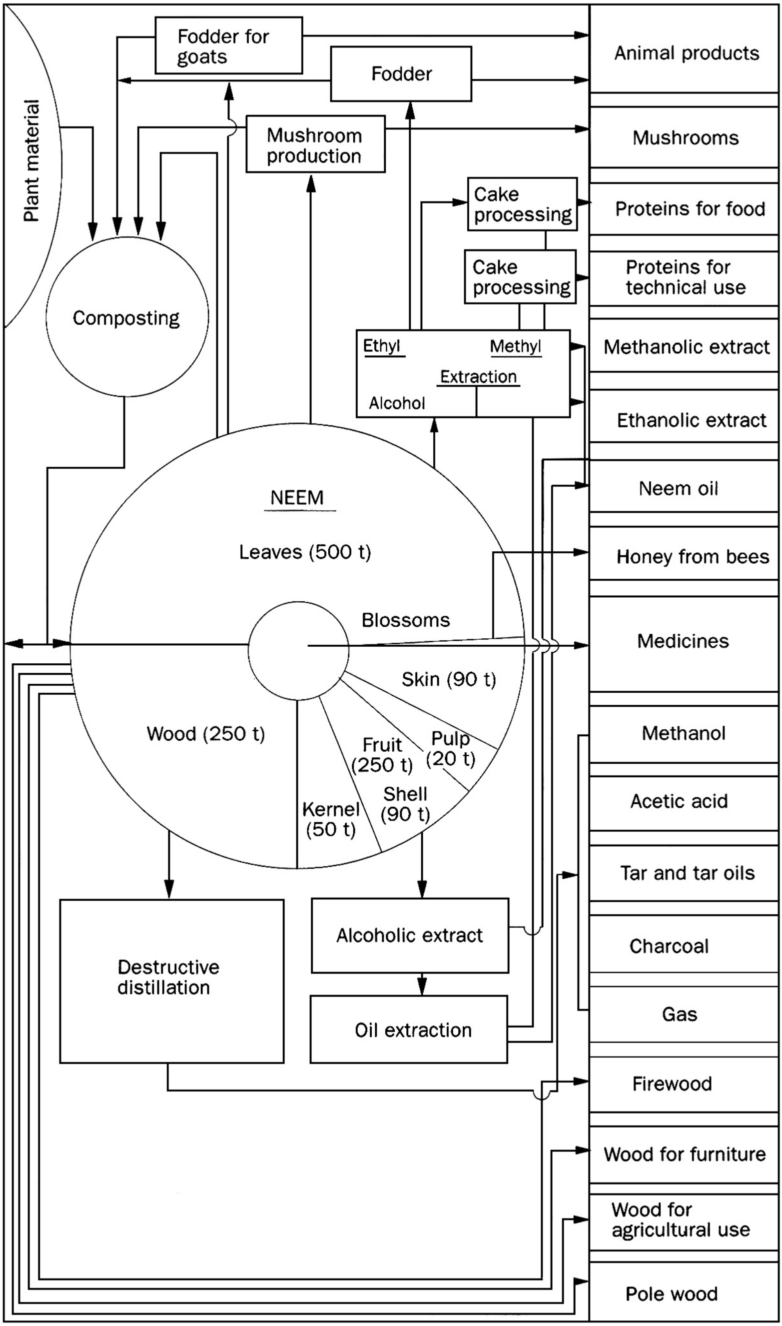
Table 21. Constraints to the development and use of neem in rice and rice-based crops (Librero et al 1988, IRRI 1989).

Product effectiveness, quality, access, and handling
- Insufficient data and demonstrations on cost effectiveness under farm conditions
- Slow pest-killing (knock down) effect
- Difficulty in accessing neem pesticides; sometimes not available at all
- Available products not sufficiently standardized, hence quality varies; crude neem materials show high variation
- Crude neem materials usually need to be transported and stored in larger quantities and are more cumbersome to handle than synthetic pesticides

Farmer perception
- Neem pesticides perceived as ineffective due to lack of quick-killing effect
- Some affluent farmers tend to avoid using crude neem materials for fear of being labeled "backward" by neighbors
- Compared with synthetic pesticides, preparing crude neem extract very time-consuming

Technical
- Lack of technical Information on products
- Lack of training to help farmers use neem effectively
- Lack of official recommendations for using neem in pest control
- Lack of organized marketing or promotion system

In India, neem trees, because of historical and cultural reasons, are abundant, but most countries have low access to neem materials. Philippine rice farmers, for example, do not have access to neem products in local markets and few neem trees grow in the country. In such cases, in-country neem pesticide production would take years to develop even if neem plantations were established immediately.



10. Possible outputs from a small-scale local neem processing plant (Michel-Kim and Brandt 1982).

Chapter 6

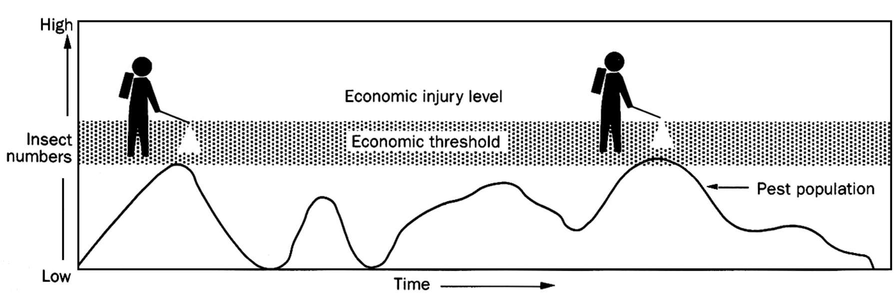
Neem use in integrated pest management (IPM)

How IPM works

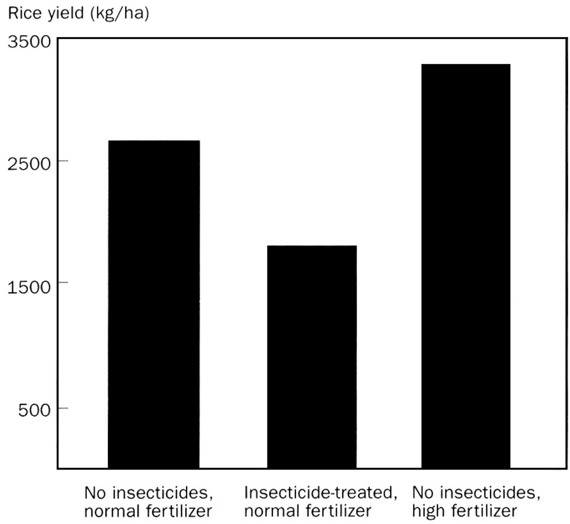
In IPM, pesticides are used only when their benefits are known to exceed economic, environmental, and social costs. Action is taken only as needed to prevent a pest population from reaching an unacceptable density commonly known as the "economic injury level." This level can be viewed as the "break-even point," below which the cost of control is not justified (Fig. 11). The level at which control measures are actually applied to prevent a pest population from reaching the economic injury level is commonly called the "economic threshold." Monitoring fields regularly and applying pesticides based on economic threshold criteria can greatly reduce and even eliminate chemical use (Oka 1989).

Sometimes when insecticides are not used, rice yields may be even higher than in treated rice (Fig. 12). Plants are remarkably adaptive in compensating for pest injury and may completely recover from an attack. Further, there is no guarantee that pesticides will control pests adequately. Sometimes, as discussed in Chapter 2, insecticides may cause pest outbreaks by killing off important natural enemies, resulting in more harm than good. In IPM, guidelines establish when to use pesticides and how to avoid problems when they are used.

All methods and practices should be considered for an IPM program. Preventive measures such as pest-resistant crop varieties, biological control agents, and cultural control techniques, such as planting high quality clean rice seeds, ensuring good water



11. When to use pesticides in integrated pest management (ADB 1987).



12. Rice yields (14% moisture content) from farmers' fields receiving different treatments, Tieng Glang, Mekong Delta, Vietnam, 1991 (Kenmore 1991).

management, and using correct fertilizers, must be considered. Pesticides are used only after monitoring shows that pests are approaching threatening numbers and that natural controls and preventive measures will not stop them. Table 22 shows the general steps for developing an IPM program.

In many parts of Asia, IPM has been introduced into rice previously treated heavily with insecticides (Kenmore 1991). In Indonesia, IPM specialists and trainers have trained about 3,000 extension workers and 150,000 farmers in IPM (Gallagher 1992). In some districts, 60-70% of the farmers who underwent IPM training have, in turn, trained other farmers (Wardhani 1992). At least 300,000 farmers nationwide were trained by other farmers.

The IPM program in Indonesia was started in November 1986 by Presidential Instruction No. 3, a presidential decree which banned the use of 57 trade formulations of insecticides and made IPM available to farmers. Farmers trained in IPM have substantially reduced the use of insecticides and costs for pest control and yields have not decreased. In many farms, yields have actually increased (Fig. 13). Nationwide, insecticide use has dropped by about half since the program started, saving the government about US$120 million annually in insecticide subsidies to farmers (Indonesian National IPM Program 1991).

The status of using neem pesticides in IPM programs

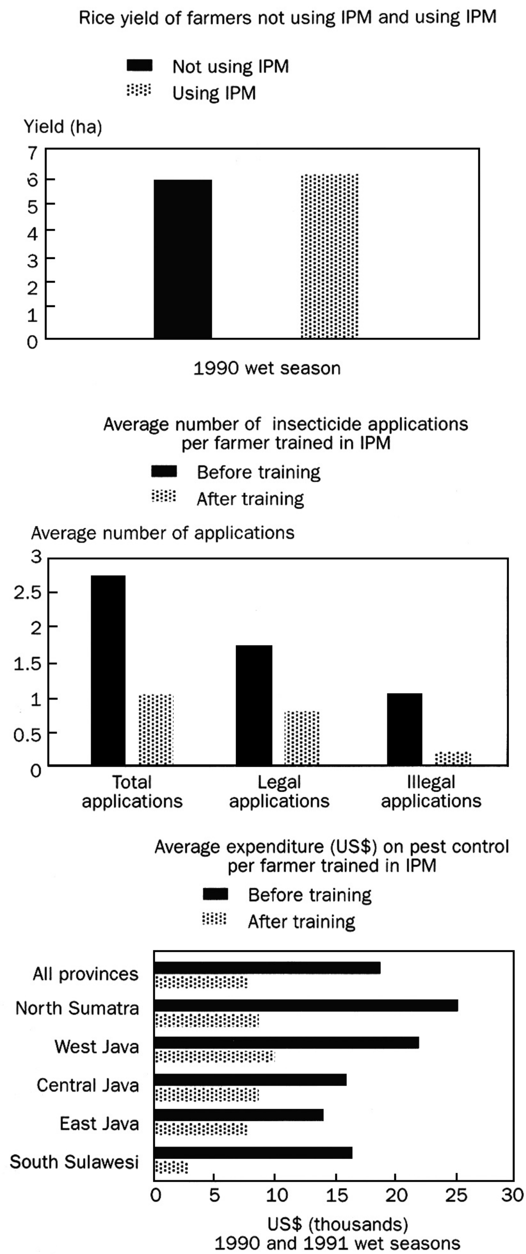
Neem experts often stress the importance of using neem pesticidal materials according to IPM principles (e.g., Schmutterer 1990a). However, a survey conducted by Lim and Bottrell (1991) showed that neem materials were being promoted as prophylactic

Table 22. General steps for developing an IPM program (Bottrell et al 1991).

Step	Needed action
One	*Identify major pests and establish criteria for taking action against them* Consider an organism threatening only when firm evidence is available to show when, where, and at what level it should be controlled.
Two	*Select the best mix of control techniques* First consider resistant crop varieties, naturally occurring biological control agents, and cultural practices. Use pesticides as a last resort to keep the pests from causing unacceptable losses.
Three	*Monitor fields regularly* Monitor crops regularly to determine the levels of pests, natural enemies, and crop damage. Teach farmers how to monitor crops for pests, natural enemies, and crop damage and how to determne when crop protection measures are necessary.
Four	*Use all control methods correctly and safely* Teach farmers the advantages and disadvantages of each pest control method. They must also learn the correct and safe use of all control methods.
Five	*Comply with all legal controls* Legal controls include quarantines to prevent entry and establishment of new pests, local laws and regulations that govern pesticides, laws relating to international transport and marketing of produce Infested with pests or treated with pesticides.
Six	*Develop educational training, and demonstration programs for farmers and extension workers* Implementation of IPM depends heavily on education, training, and demonstrations to help farmers and extension workers develop, implement, and evaluate IPM methods. Conduct practical hands-on training in farmers' field schools. Develop special trainlng for extension workers and educational programs for government officials and the public.

treatments and not on the basis of need as determined by monitoring and considering the net returns to farmers.

Therefore, in 1991, the IRRI-ADB botanical pest control project took steps to asssess the value of neem in IPM systems on farmers' fields (IRRI 1991, 1992; Appendix 2). Project collaborators agreed to conduct trials to compare neem use with synthetic insecticides in IPM. These treatments were compared to farmers' practice of treating rice prophylactically with insecticides. Trials were conducted in large replicated plots on farmers' fields in several countries. In Tamil Nadu, India, for example, results of IPM treatments using neem showed that major insect pests (e.g., brown planthopper, green leafhopper *Nephotettix* sp., yellow stem borer, and gall midge *Orseolia oryzae*) did not exceed economic injury levels. Leaffolders *Cnaphalocrocis medinalis* and *Marasmia* sp. did exceed the economic injury level at 53 d after transplanting and required one application of neem or synthetic insecticide. By comparison, the farmers' practice using no IPM included three applications of insecticide. Results from IPM trials that used neem in farmers' fields were similar at



13. Impact of IPM on rice yield, insecticide use, and pest control costs in Indonesia, based on practices of 2,013 farmers in 6 provinces (Indonesian National IPM Program 1991).

four different locations in Tamil Nadu (Table 23). On average, rice yield was 20.5% more and income was US$119.77/ha more under IPM treatments using neem than under farmers' practice treatment. Yields and increased incomes were only slightly less under IPM treatment using neem than under IPM treatment using synthetic insecticides.

Results from IPM trials at other locations are not available for rice or other crops grown in association with rice. While the results using neem in the IPM program at Tamil Nadu are encouraging, more IPM trials on farmers' fields are needed at Tamil Nadu and at other locations. These should be repeated over several seasons and be subjected to critical economic analysis before conclusions can be drawn about the neem's potential in IPM.

IPM training

The successful implementation of IPM depends heavily on training and demonstrations to help farmers and extension workers develop and evaluate IPM methods (Kenmore 1991). Practical hands-on training in farmers' fields is particularly important. Rice farmers with proper IPM training almost always use less insecticide, spend less on pest control, have fewer problems with pest outbreaks, and produce higher yields than farmers with no IPM training. This was illustrated in the successful Indonesian IPM program (Fig. 13) and also in Sri Lanka (Table 24).

Making farmers aware of the potential and limitations of neem pest control technologies is important in areas such as India where these technologies are being used by farmers. Through support from the IRRI-ADB botanical pest control project (IRRI 1991, 1992), farmer training on the use of neem (and other botanicals) was conducted by TNAU in collaboration with the Department of Agriculture in Tamil Nadu. The *mela* (or farmers' meeting) method was emphasized. Training included an

Table 23. Comparison of average rice yields and incomes from neem-incorporated IPM and farmers' practice (no IPM) at different locations in Tamil Nadu, India, 1991-92 (S. Jayaraj, TNAU, Coimbatore, India, unpubl. data).[a]

Location	Yield (kg/ha)			Yield increase over farmers' practice (%)		Increase in net income over farmers' practice (US$/ha)	
	Farmers' practice	IPM (SI)	IPM (NSKE)	IPM (SI)	IPM (NSKE)	IPM (SI)	IPM (NSKE)
Aduthurai	7092	7971	7820	12.4	10.3	66.28	49.18
Coimbatore (Gobichettlpalayam)	4446	5000	4964	14.7	11.7	24.86	32.43
Thanjavur							
(Vaidyanathampatti)	5010	7428	7242	48.3	44.6	262.43	250.86
(Rajendran)	7316	9064	8730	23.9	19.3	177.02	146.63
Mean	5966	7366	7189	23.5	20.5	132.65	119.77

[a] For each treatment, field was about 0.4 ha. IPM (SI) = IPM using synthetic insecticide IPM (NSKE) = IPM using neem seed kernel extract.

Table 24. Area cultivated, brown planthopper-affected area, insecticide use, and yield for IPM trained and untrained farmers in the brown planthopper outbreak season in Polonnaruwa District, Sri Lanka (1989-90 maha wet season) (Kenmore 1991).

Variable	Farmers with IPM training	Farmers with no IPM training
Area cultivated (ha)	1.8	1.8
Percent of cultivated area affected by brown planthopper[a]	18.8	48.6
Number of insecticide applications per season[a]	0.6	1.6
Cost of insecticides in the season (US$/ha)[a]	5.16	16.56
Amount of insecticide used in the season (ml formulated product/ha) [a]	356.0	1526.0
Yield (kg/ha) [a]	4654.0	3455.0

[a] Means in a row are significantiy different at the 1% level.

14. A *mela* (dialogue session) on botanical pest control with farmers in Ambarampalayam, Tamil Nadu, 1991 (Jayaraj 1992).

exhibition of botanical products, demonstration of their use, lectures on natural enemies, and a question-and-answer session with farmers (Fig. 14).

From January 1991 to July 1992, 42 *mela* sessions provided training to 5,565 farmers (Jayaraj 1992). In addition, four training sessions were organized for 40 extension personnel and two sessions for 30 private company personnel. A neem day and neem week also were organized in all 20 districts of Tamil Nadu.

TNAU considers the *mela* approach to be highly effective in promoting proper use of neem and other botanical pest control products.

Chapter 7

Botanical pesticides other than neem

Of the many botanical pest control products used in rice-based crops, neem is the best known. A 1987 survey in 12 provinces in the Philippines found that farmers had used or were aware of 76 plant species for pest control (IRRI 1989). Of the farmers surveyed, 72% had used Mexican lilac *Gliricidia sepium:* 31%, common reed *Saccharum spontaneum;* 27%, moonseed *Tinospora rumphii;* 15%, *Alpinia* (= *Kolowratia*) *elegans;* 6%, wild basil, also known as bush-tea *Hyptis suaveolens;* and 4%, derris *Derris elliptica* (Librero et al 1988). Another survey of 350 farmers indicated that Mexican lilac and red pepper *Capsicum frutescens* had been commonly used in the past (IRRI 1989). Farmers poked twigs of Mexican lilac 6-8 m apart in ricefields to control stem borers (species not indicated) and sprayed water extract of red pepper to control rice bugs *Leptocorisa* spp.

Botanical pest control in the Philippines and in some other rice-producing countries, once common, has declined in recent years. With the shift toward synthetic pesticides, suitable plant materials are more and more difficult to obtain. Farmers also lack confidence in plant pest control agents (Librero et al 1988).

Effectiveness of other plant materials

Extract of turmeric *Curcuma longa* has been tested against several rice insect pests (Saxena 1980). The small dose of 5 µg/brachypterous female was sufficient to kill brown planthopper and whitebacked planthopper. Adults of green leafhoppers *N. virescens* were less susceptible, but young nymphs were highly sensitive. However, treated rice yielded no more than untreated rice.

Turmeric extract was effective against third-instar nymphs of rice bugs *Leptocorisa* sp. and reduced egg hatching in that species. It also killed adults and eggs of the whorl maggot *Hydrellia philippina* (= *sasakii*); reduced egg hatch of the rice caseworm *Nymphula depunctalis* and green hairy caterpillar *Rivula atimeta;* stimulated abnormal development of fifth-instar larvae of striped stem borer; and reduced oviposition, disrupted embryonic growth, changed feeding behavior, and reduced survival in the leaffolder *C. medinalis* (Saxena 1980).

During storage, rice grains treated with oils of turmeric and sweetflag *Acorus calamus* repelled red flour beetles *Tribolium castaneum* (Jilani et al 1988). Treated adults produced fewer and underweight progenies. Adults of the lesser grain borer *Rhyzopertha dominica* were also repelled and made fewer feeding punctures.

Turmeric extract also inhibited the growth of four bacterial and five fungal pathogens (Saxena 1980). The bacteria included the agents causing bacterial leaf blight *Xanthomonas oryzae* (=*campestris*) pv. *oryzae,* bacterial leaf streak *Xanthomonas oryzae* (=*translucens*) pv. *oryzicola* (=*oryzae*), soft rot *Erwinia carotovora,* and bacterial wilt *Pseudomonas solanacearum.* Extracts at ≥5 mg/12-mn-diamfilter paper disc significantly inhibited fungal pathogens of leaf scald *Rhynchosporium oryzae,* narrow leaf spot *Cercospora oryzae,* rice blast *Pyricularia oryzae,* and sheath rot *Acrocylindrium oryzae* (Saxena 1980). Turmeric inhibited the mycelial growth of rice blast as well as germination of conidiospores. However, the extract was ineffective against the causal agent of bakanae disease Fusarium *moniliforme* and brown spot *Drechslera* (=*Helminthosporium*) *oryzae* even at high doses (Saxena 1980).

The oil of karanja (also known as Indian beech or pongram) *Pongamia pinnata* (=*glabra*) repelled brown planthopper and significantly reduced its ingestion and assimilation of food (IRRI 1985). The growth of exposed nymphs appeared to be retarded, but adult longevity, fecundity, oviposition, and egg hatching were unaffected. Both brown planthopper and whitebacked planthopper suffered high mortality rates, but green leafhopper *Nephottetix* sp. was less susceptible. The oil treatment affected the predatory green mirid bug *C. lividipennis* slightly, but had no effect on the wolf spider *Pardosa pseudoannulata.* Turmeric oil repelled leaffolder *C. medinalis* larvae and with increasing concentrations food intake progressively decreased. Hatching was reduced when leaffolder eggs were dipped in 3% or higher concentrations of the oil. Food intake of rice caseworm was reduced and its development impaired when larvae were fed sprayed rice leaves. However, hatching was not affected even when the eggs were dipped in turmeric oil (IRRI 1985).

Numerous other plants, including Alexandrian laurel *Calophyllum inophyllum,* mahua *Madhuca longifolia,* chinaberry *Melia azedarach, Hydnocarpus* sp., and moonseed, have been evaluated for their potential against rice pests (IRRI 1989, 1991, 1992).

Effects on nontarget species

Like neem, other botanical pest control agents have had a range of effects on nontarget organisms. The predatory green mirid bug *C. lividipennis* was susceptible to high doses of turmeric, but the spider *P. pseudoannulata* did not die in significant numbers. Ripple bug *Microvelia douglasi atrolineata* was not adversely affected when confined in extract-contaminated water (Saxena 1980).

Some plant species appear to be much more toxic to nontarget organisms than neem. An example is endod *Phytolacca dodecandra,* also called soapberry, a plant with molluscicidal properties highly toxic to fish and other beneficial aquatic organisms (UNFSSTD/IDRC 1986). Endod is toxic to the water flea and significantly reduces water flea reproduction at concentrations greater than 0.25 mg/liter. Endod is also toxic to the alga *Selenastrum capricornutum* (Lambert et al 1990) and some warm-blooded animals (Lambert et al 1990, UNFSSTD/IDRC 1986). However, oral administration of crude water extract from the plant (at field-level molluscicidal concentrations of 5-100 mg/liter) did not harm humans (UNFSSTD/IDRC 1986).

Table 25. Some highly toxic plant species in Malaysia (Salam Abdullah 1990).

Common and scientific names	Effects
Yellow oleander *Nerium olander*	Affects the heart. Horses, cattle, and sheep die after eating the leaves in quantities as little as 0.005-0.015% of their body weight. A single leaf is potentially lethal to humans. Affected humans may be dizzy and drowsy. Terminally, heartbeat becomes progressively weaker and irregular, leading to dyspnoea and coma.
Lantana or white sage *Lantana camara*	Affects the liver. Contains a number of triterpenes. Toxic to sheep when given orally at 60 mg/kg body welght. Lantana toxicity is normally subacute. Affected animals show toxic signs, such as depression and anorexia, a few days after ingesting. Death occurs a few weeks later and may be due to renal failure.
Thorn apple *Datura fastuosa*	Affects the nervous system. All plant parts are toxlc. The active principle is daturine which contains alkaloids whlch act centrally and peripherally, resulting in anti-cholinergic manifestation. Effects are immediate. Death is due to respiratory paralysis. A fatal dose is 100-125 seeds.
Sweet-scented calophyllum *Calophyllum inophyllum*	Causes purgation and emesis. Seeds contain about 75% oil, which is an irritant and rubefacient. Leaves contain saponin and hydrocyanic acid. Resin from the wood is emetic and purgative. Ingesting seeds may cause nausea, vomiting, and diarrhea. The sap irritates the skin and eyes, and is fatal if given Intravenously.
Tufted fishtall palm *Caryota mitis*	Produces skin and respiratory irritants. Contact causes painful inflammation and itching of the skin that may last for hours.
Cassava or tapioca *Manihot esculenta*	Cyanogenetic plant that accumulates cyanide in the form of cyanogenetic glycoside whlch liberates free cyanide upon hydrolysis. Ingesting 4-5 mg of hydrocyanic acid (HCN)/kg body weight per h is lethal. Some plants may harbor 760 ppm of cyanide (as HCN). HCN inhibits prophyrin, the respiratory enzyme. Affected subject generally dies of asphyxiation at the cellular level. Cooking denatures HCN.

Numerous plant species not used for pest control are known to be highly toxic to humans and other mammals (Salam Abdullah 1990). Pokeweed *Phytolacca americana* is highly poisonous to sheep *Ovis aries,* and the old practice of using its berries to color wines has been prohibited in some places because of the possible danger to humans (Chopra et al 1965). Powdered leaves of sweet belladona *Phytolacca acinosa* can cause delirium, while eating its boiled leaves without discarding the water causes severe poisoning (Chopra et al 1965). Table 25 gives further examples. The toxicology (mode of action) for most species is not clearly understood.

Future exploitation of other plants

As part of an effort to seek effective alternatives to synthetic pesticides, research institutions should examine the potential of plants other than neem. The rapid disappearance of naturally forested land and the abandonment of traditional pest control practices in the tropics add to the importance of this work. Both of these events probably contribute to diminished prospects of discovering promising new species

Chapter 8

Lessons learned and the next steps

Neem has long been used for pest control and is still used by farmers today. Many national institutions now have research programs to further exploit neem-based pest control, and Asian, US, and European corporations now offer a range of commercial neem pesticides. Enthusiasm is strong and in many ways present-day use of neem resembles the 1950s and 1960s when synthetic pesticides were being exploited prophylactically with few questions asked about their long-term contributions and possible side effects (Bottrell 1991). A recent survey of neem pest control researchers in South and Southeast Asia showed clearly that most work focuses on efficacy trials (Lim and Bottrell 1991). Relatively little work evaluates the effects of neem on nontarget organisms, determines its performance in IPM programs, or measures its costs and benefits to farmers.

Needed action

Socioeconomic studies. The value of neem in rice pest control should be based on more than its ability to achieve a certain level of pest suppression. A product that kills a high percentage of target pests is not necessarily a farmer's best investment. More important is how much the control method contributes to increased farmer profit, sustained crop production, and environmental and human safety.

Cost-benefit ratios and partial budgets that estimate farmer profitability are needed to show whether neem is more cost-effective than synthetic pesticides. Any such estimates should be derived from trials in farmers' fields in representative areas. The analysis should also include the social factors influencing farmer acceptance.

IPM farm trials. Most studies have emphasized the use of neem products for prophylactic treatment, clearly defying the main thrust of IPM. Only since the IRRI-ADB botanical pest control project (IRRI 1991, 1992), has there been much effort to evaluate the materials in rice IPM farm trials as discussed in Chapter 6. These trials should be continued and expanded to additional areas.

Farmer training and participation. Training programs are essential in areas of India and other countries where institutions are promoting neem products for pest control. Farmers especially need guidance on correct preparation and use of the materials as well as on their limitations. The *mela* system discussed in Chapter 6 may be appropriate in locations other than Tamil Nadu where it was developed.

Environmental impact studies. A good start has been made on measuring the effects of neem on nontarget organisms in rice and crops grown in rice-based systems (IRRI 1991, 1992). Neem appears to be safer against most nontarget organisms than the synthetic pesticides to which it has been compared. However, neem clearly can harm some nontarget species (IRRI 1991, 1992). More work is needed to determine neem's effects on a broader range of nontarget organisms that inhabit rice and the surrounding environments, and in more locations. Both "no effect" and "slight effect" levels of a product should be determined, particularly for parasitoids and predators. It is also important to differentiate between laboratory and field experiments because some products, such as neem oil, may have different effects in laboratory and field environments. For example, neem had a strong growth-regulating effect on larvae of the predators green lacewing C. *carnea* and ladybird beetle *Coccinella septempunctata* in the laboratory, but not in the field (Schmutterer 1990a). Studies should be evaluated according to standard testing protocols and should determine short- and long-term (multiple-generation) effects, including the effects on behavior and fitness (IOBC/ WPRS 1988).

Effects on representative species of pollinators, fishes, frogs, birds, and other nontarget organisms should also be evaluated.

Pest resurgence and resistance studies. Research has confirmed that many chemical pesticides may cause pest resurgence, resulting in increased rather than decreased pest populations. This is because the natural enemies of pests are killed and pest fecundity is stimulated. Investigations are needed to determine if neem pesticides will cause resurgence of pests. The IRRI-ADB botanical pest control project (IRRI 1991, 1992) started some of these investigations. Preliminary results by the Directorate of Rice Research in Hyderabad, India, showed no resurgence of brown planthopper after treatment with neem, but treatment with the synthetic insecticide deltamethrin (Decis) generated massive brown planthopper buildups, which resulted in total hopperburn. Treatment with monocrotophos (Azodrin 202 R) resulted in 43.5% hopperburn. More studies need to be conducted.

Some researchers (e.g., Saxena 1989) believe that insect resistance to neem products is unlikely. This is because neem has multimortality and multibehavior-modifying modes that are more difficult for the pest to defy than single-mode mechanisms. In contrast, other researchers (e.g., Larew 1992) believe that increased use will result in resistance to neem.

Vollinger (1987) experimentally explored the possibility of the diamondback moth becoming neem-resistant. Two genetically different insect strains were treated with purified neem seed kernel extract and with deltamethrin (Decis) for up to 42 generations. Results showed no sign of resistance in the neem-treated population, while the two deltamethrin-treated populations developed 20-fold and 35-fold resistance. No cross-resistance occurred between deltamethrin, neem extracts, and diflubenzuron in the deltamethrin-resistant populations, and esterase enzyme activity did not change significantly over 35 generations.

However, this single study is not sufficient to conclude that pests will not evolve neem-resistant strains. The lesson of insect pests developing resistance to the pathogen

Bacillus thuringiensis (Bt) should serve as a useful reminder. It was assumed that insects would not become resistant to *Bt* because it is a biological agent. An experimental study by Devriendt and Martouret (1976), similar to that of Vollinger (1987) for neem, initially lent support to this assumption. However. as field populations of the diamondback moth were repeatedly exposed to commercial *Bt* sprays in Hawaii, high levels of resistance appeared, nullifying the pathogen's usefulness (Tabashnik et al 1990). There are signs that resistance to the bacterium is also developing in parts of Southeast Asia (Miyata et al 1988).

This points to the need for more scientific investigations on the possibility of developing neem resistance.

Seeking better quality neem trees. Selection and breeding programs may improve the quality and yield of neem products. The Forest College and Research Institute (Mettupalayam) of TNAU has collected a range of neem germplasm, mainly from Tamil Nadu. This collection needs to also include germplasm materials from more areas of India as well as other countries.

Phytotoxicity problems. Phytotoxicity limits neem use, especially neem oil. Phytotoxicity occurs quite commonly at doses that are effective against pests (Schmutterer 1990a). For example, Loke et al (1990) found phytotoxicity to be severe to cabbage *Brassica oleracea capitata,* killing all plants treated with 3% and stronger concentrations of neem oil. Plants surviving the lower concentration treatments were scorched and retarded. Mustard *Brassica juncea* plants treated with 3% of neem oil had a 30% mortality rate and those treated with 4% neem oils a 40% mortality rate (Loke et al 1990). Surviving plants were scorched, retarded, and yielded significantly less than nontreated plants. However, rice plants were less affected. Scorching only occurred at 2% and stronger concentrations of neem oil (Loke et al 1990). All plants survived and produced a yield not significantly different from that of untreated control. However, rice grains ripened unevenly.

It is important to find ways to minimize these *phytotoxic* effects.

Synergism effects. Recent studies have shown the potential of using neem and other materials as synergists to enhance the effects of microbial pest control agents. Researchers at the TNAU determined that extracts ofthe plants *Prosopis* spp. and *Vitex negundo* increased the effectiveness of the nuclear polyhedrosis virus as a pathogen against the insect pest cotton bollworm *Helicoverpa armigera* (S. Jayaraj, TNAU, Coimbatore, India, unpubl. data). Use of botanicals combined with biological control agents needs to be investigated further.

New productformulations. Socioeconomic surveys in India showed that the lack of reliable and standardized formulations for neem products is an important constraint to increased use. Products that are effective and easy to use must be readily accessible. Efforts to formulate products, which give consistently reliable results and which farmers can afford, need attention.

Concludingremarks

A major reason for the increasing interest in botanical pest control in rice-based cropping systems, specifically neem. results from mounting problems with, and failures from, synthetic pesticides. However, it must be remembered that most concentrated neem derivatives probably function like mixtures of synthetic pesticides (Larew 1992). The bioactive principles are active chemical constituents. Plant active principles, particularly when concentrated into pest control products, may even be more toxic or disruptive than synthetic pesticides. They, like any intervention, need to be used judiciously within a holistic framework of IPM. The future of neem and other botanical pesticides will be judged on how successfully they achieve positive pest control in economically, socially, and environmentally acceptable IPM systems.

IRRI and ADB took a major step to move neem (and by implication other botanicals) into the IPM context (IRRI 1991, 1992). However, more needs to be done before neem can be used in IPM at the farm level. National programs are now well qualified to carry out further work on neem in rice-based cropping systems. Neem research is likely to continue in many places. It is hoped that the IRRI-ADB effort helped to establish guidelines for future evaluations important to institutions interested in botanical pesticides from an IPM perspective.

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Appendices

Appendix 1. Scientific and common names (if available) of organisms mentioned in the test.

Plants

Abelmoschus esculentus (okra)
Acorus calamus (sweetflag, calamus)
Alpinia (= *Kolowratia*) *elegans*
Annona squamosa (custard apple, sweetsop)
Arachis hypogaea (peanut, groundnut, goober)
Azadirachta indica (= *Antelaea azadirachta,*
    Melia azadirachta) (neem, nim, margosa tree, Indian lilac)
Brassica juncea (mustard)
Brassica oleracea capitata (cabbage)
Calophyllum inophyllum (Alexandrian laurel, sweet-scented calophyllum)
Capsicum frutescens (red pepper, chili pepper, tabasco pepper)
Caryota mitis (tufted fishtail palm)
Cicer arietinum (chickpea)
Coix lachryma-jobi (millet)
Corchorus olitorius (jute)
Curcuma longa (turmeric)
Datura fastuosa (thorn apple)
Derris elliptica (derris)
Gliricidia sepium (Mexican lilac)
Glycine max (soybean)
Gossypium hirsutum (cotton)
Helianthus annuus (sunflower)
Hordeum vulgare (barley)
Hydnocarpus sp.
Hyptis suaveolens (wild basil, bush-tea)
Lantana camara (lantana, white sage)
Lens culinaris (lentil)
Lycopersicon esculentum (tomato)
Madhuca longifolia (mahua)
Manihot esculenta (cassava, tapioca plant)
Melia azedarach (chinaberry)
Nerium olander (yellow oleander, common oleander)

Oryza sativa (rice)
Phacelia tanacetifolia (tansy phacelia)
Phaseolus mungo (mungbean)
Phytolacca acinosa (sweet-scented belladona)
Phytolacca americana (pokeweed, pokeberry)
Phytolacca dodecandra (endod, soapberry)
Pongamia pinnata (=*glabra*) (pongram, karanja, Indian beech)
Prosopis spp.
Saccharum spontaneum (common reed)
Sesamum indicum (sesame, gingely-oil plant)
Solanum tuberosum (potato)
Sorghum bicolor (cholam)
Tinospora rumphii (moonseed)
Triticum aestivum (wheat)
Vigna mungo (black gram)
Vigna unguiculata (cowpea)
Vitex negundo (Indian privet, five-leaved chaste tree)
Vitis sp. (grape)
Zea mays (maize, corn)

Plant pathogens
Acrocylindrium oryzae (sheath rot)
Aspergillus flavus (aflatoxin-producing fungus)
Cercospora oryzae (narrow brown leaf spot)
Drechslera (=*Helminthosporium*) *oryzae* (brown spot)
Erwinia carotovora (soft rot)
Fusarium moniliforme (bakanae)
Pseudomonas solanacearum (bacterial wilt)
Pyricularia oryzae (rice blast)
Sarocladium oryzae (sheath rot fungus)
Rhynchosporium oryzae (leaf scald fungus)
Xanthomonas oryzae (=*campestris*) pv. *oryzae* (bacterial leaf blight)
Xanthomonas oryzae (=*translucens*) pv. *oryzicola* (bacterial leaf streak)

Insect and mite pests
Aedes aegypti (mosquito)
Aphis gossypii (aphids)
Bemisia tabaci (sweet potato whitefly)
Chilo suppressalis (striped stem borer)
Cnaphalocrocis medinalis (rice leaffolder)
Helicoverpa armigera (cotton bollworm)
Hydrellia philippina (=*sasakii*) (whorl maggot)
Leptinotarsa decemlineata (Colorado potato beetle)
Leptocorisa spp. (rice bugs)
Marasmia patnalis (rice leaffolder)
Marasmia spp. (rice leaffolders)
Melanaphis sacchari (aphids)
Nephotettix spp. (rice green leafhoppers)

Nephotettix virescens (rice green leafhopper)
Nilaparvata lugens (rice brown planthopper)
Nymphula depunctalis (rice caseworm)
Orseolia oryzae (rice gall midge)
Plutella xylostella (diamondback moth)
Rhyzopertha dominica (lesser grain borer)
Rivula atimeta (green hairy caterpillar)
Scirpophaga incertulas (rice yellow stem borer)
Scirpophaga innotata (rice white stem borer)
Scotinophara coarctata (Malayan black bug)
Sogatella furcifera (whitebacked planthopper)
Spodoptera litura (common cutworm)
Tetranychus cinnabarinus (carmine spider mite)
Triboluim castaneum (red flour beetle)

Predators (insects, spiders, and mites)
Anaxipha longipennis (sword-tail cricket)
Chiracanthium mildei (clubionid spider)
Chrysopa carnea (green lacewing)
Coccinella septempunctata (ladybird beetle)
Conocephalus longipennis (meadow grasshopper)
Cyrtorhinus lividipennis (green mirid bug)
Delphastus pusillus (coccinellid beetle)
Mesovelia orientalis (water treader bug)
Metioche vittaticollis (black cricket/gryllid)
Micraspis hirashimai (lady beetle)
Micraspis spp. (lady beetles)
Microvelia douglasi atrolineata (ripple bug)
Ophionea nigrofasciata (ground beetle)
Oxyopes javanus (lynx spider)
Pardosa pseudoannulata (wolf spider)
Phytoseiulus persimilis (phytoseid mite)
Tytthus parviceps (black mirid bug)

Parasitoids
Cotesia plutellae (braconid wasp)
Diadegma semiclausum (ichneumonid wasp)
Eretmocerus californicus (aphelinid wasp)
Goniozus triangulifer (bethylid wasp)
Lysiphlebus testaceipes (braconid wasp)
Telenomus remus (scelionid wasp)
Telenomus rowani (scelionid wasp)
Testrastichus howardi (synonyms, *T. ayyari* and T. *israeli*) (eulophid wasp)
Trichogramma japonicum (trichogrammatid asp)

Nematodes
Ditylenchus angustus (stem nematode)
Meloidogyne incognita (root-knot nematode)

Meloidogyne javanica (root-knot nematode)
Meloidogyne spp. (root-knot nematodes)

Earthworm
Eisenia foetida (earthworm)

Crustaceans
Daphnia magna (water flea)
Heterocypris luzonensis (ostracod)

Alga
Selenastrum capricornutum

Birds
Colinus virginianus (bobwhite quail)
Anus platyrhynchos (mallard duck)

Fish
Cyprinus carpio (carp)
Lepomis macrochirus (bluegill sunfish)
Salmo gairdneri (rainbow trout)
Lebistes reticulatus (guppy)
Oreochromis mossambicus (Java tilapia)
Oreochromis niloticus (Nile tilapia)

Others
Apis mellifera (honey bee)
Bacillus thuringiensis (Bt)
Bufo sp. (toad)
Cavia porcellus (guinea pig)
Oryctolagus cuniculus (rabbit)
Ovis aries (sheep)
Rana hexadactyla (frog)
Rana limnocharis (frog)
Rattus sp. (rat)

Appendix 2. IRRI-ADB botanical pest control project: areas of study undertaken by collaborators.[a]

Collaborators[b]	Areas of study[c]									
	1			2			3	4	5	6
	R	C	P	Nt	Re	Rs				
BRRI	+		+	+	+	+			+	
SCAU	+									
CNRRI	+									
TNAU	+	+	+	+	+	+	+	+	+	+
IGAU	+									
DRR				+	+	+				
RAU	+									
BORlF	+		+							
NARC	+		+				+			
PARC	+									
PTRRC	+									
PhilRice	+		+							
BSU				+	+					
IRRI				+	+					

[a] The project's official name was Technical Assistance for Strengthening of Rice Crop Protection Research and Minimizing Environmental Damage in Developing Countries, Phase II (Asian Development Bank Technical Assistance #5349).
[b] BRRI = Bangladesh Rice Research Institute (Bangladesh), SCAU = South China Agricultural University (China), CNRRI = China National Rice Research Institute (China), TNAU = Tamil Nadu Agricultural University (India), IGAU = Indira Gandhi Agricultural University (India), DRR = Directorate of Rice Research India, RAU = Rajendra Agricultural University (India), BORIF = Bogor Research Institute for Food Crops (Indonesia), NARC = National Agricultural Research Center (Nepal), PARC = Pakistan Agricultural Research Council (Pakistan), PTRRC = Pathum Thani Rice Research Center (Thailand), PhilRlce = Philippine Rice Research Institute (Philippines), BSU = Benguet State University (Philippines), and IRRI = International Rice Research Institute. [c] 1 = Efficacy evaluation and farmer field trials. R = rice, C = cotton, and P = pulses, 2 = Environmental impact studies. Nt = nontarget organisms, Re = resistance development and Rs = resurgence, 3 = Socioeconomic studies, 4 = IPM evaluation and implementation. 5 = Training and farmer participation 6 = Biotechnology

Appendix 3. IRRI-ADB botanical pest control project: studies on the impact of neem on nontarget organisms, insect pest resistance, and insect pest resurgence. [a]

Field of studies	Collaborators [b]				
	BRRI	TNAU	DRR	BSU	IRRI
Toxicity effects on nontarget organisms					
Aedes aegypti					+
Cotesia plutellae		+		+	
Chrysopa carnea		+			
Cyrtorhinus lividipennis		+	+		+
Diadegma semiclausum		+		+	
Mesovelia orientalis	+				
Micraspis hirashimai					+
Microvelia douglasi atrolineata			+		
Oxyopes javanus	+				
Pardosa pseudoannulata	+	+			
Rana hexadactyla		+			
R. limnocharis					+
Telenomus rowani					+
Tetrastichus howardi (=T. israeli)		+	+	+	
Oreochromis sp.		+			+
Trichogramma ,japonicum		+	+		
Tytthus parviceps			+		
Pest resistance studies					
Nephotettix virescens		+	+		
Nilaparvata lugens	+	+	+		
Plutella xylostella		+		+	
Pest resurgence					
N. lugens	+	+	+		

[a] The project's official name was Technical Assistance for Strengthening of Rice Crop Protection Research and Minimizing Environmental Damage in Developing Countries, Phase II (Asian Development Bank Technical Assistance #5349).
[b] BRRI = Bangladesh Rice Research Institute (Bangladesh), BSU = Benguet State University (Philippines), DRR = Directorate of Rice Research (India), IRRI = International Rice Research Institute, and TNAU = Tamil Nadu Agricultural University (India).

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