Integrated Pest Management in the Tropics

Current Status and Future Prospects

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Integrated Pest Management in the Tropics

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Current Status and Future Prospects

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Contents

List of Contributors vii

Introduction ix

Acronyms and Abbreviations xi

1 Practice of Integrated Pest Management in Tropical and Sub-Tropical Africa: An Overview of Two Decades (1970–1990) 1
O. Zethner
- Profile of African farming 1
- Development of IPM in Africa 6
- Technical and biological components of IPM 13
- IPM for multiple cropping systems 20
- IPM for pearl millet in the Sahel 25
- Sorghum IPM 29
- Cassava-based IPM 30
- Rice IPM, with special reference to Burkina Faso and Madagascar 36
- Cotton-based IPM with special reference to the Sudan 39
- Coffee IPM with special reference to Kenya 45
- IPM in cocoa with special reference to Ghana 47
- Other crops using IPM components 49
- Livestock IVM and tsetse fly control programmes 50
- Future roles for IPM 53
- IPM for stored products 56
- Prospects for IPM in Africa 56
- References 62
- Appendix: IPM and IPM-related projects in Africa 66

2 Practice of IPM in South and Southeast Asia 69
A. K. Raheja
- Current trends, policies and strategies 70
- Pesticide usage in Asia 73
- Status of IPM for rice 82

IPM in vegetables 90
IPM in cotton 94
Biological control of sugarcane pests 98
IPM in horticultural (fruit) and plantation crops 100
Status of IPM in India 101
Status of IPM in China 103
Neem in pest control 104
Management of insecticide resistance 105
IPM and the Green Revolution 107
Epilogue 109
References 111

3 Review of IPM in South America 121
C. Campanhola, G. José de Moraes and L. A. N. de Sá
Agricultural overview of South America 122
Trends in pesticide use 125
Institutional aspects of IPM development and implementation 129
Impact of regional IPM programmes 131
New ongoing IPM projects 145
Constraints to IPM use in South America 146
A look to the future 147
References 149

Executive Summary and Recommendations 153
General observations on the status of IPM in the tropics 154
Observations on the status of IPM in Africa 155
Observations on the status of IPM in Asia 157
Observations on the status of IPM in South America 159
Recommendations 160

Index 163

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Introduction

The explicit and vivid portrayal of the horrors of the overuse and misuse of pesticides in Rachel Carson's book, *Silent Spring*, served to spark public awareness that the Green Revolution was not to be fought without casualties. The high-input, chemical-intensive strategies of pest control in use in the North since the 1940s—the birth of the synthetic pesticide era—quickly spread to the countries of the South in the 1960s and 1970s, until, today, the developing world purchases about 31% of global pesticide exports. There is a clear indication that pesticide use in tropical countries, particularly in Africa, is increasing rapidly, and some evidence to suggest that a good share of this is the result of an increase in pesticide dumping (WRI, 1994).

In answer to the widespread scientific and public concern ignited in part by Carson's book, an alternative approach to pesticide use known as integrated pest management (IPM) was developed in the 1940s–1960s. IPM tackles the entire agro-ecosystem in which both the crop (or livestock host) and pest are but two components. Different tactics are used in developing site-specific management systems that capitalise on natural biological factors that serve to maintain the pests at levels below those causing economic loss ('injury'). Chemicals are used only as a last resort, but their dosages and application are carefully adjusted so as to minimise deleterious effects on health and the environment.

IPM makes use of all suitable tactics and techniques to keep the pests below their economic injury levels (EIL), so long as they are compatible. In this respect, monitoring of pest populations, assessing the damage and losses caused by the pests, and then setting the EILs become important supportive tactics in an IPM programme. The direct tactics (components) used may be 'preventive', serving to prevent the build-up of pest populations, or 'curative', serving to reduce pest numbers after or near the time when they have reached their economic injury levels.

Examples of direct preventive tactics include development of insect-resistant crops, cultural practices such as manipulation of crop planting patterns and combinations, and maintenance of the pests' natural enemies in farmers' fields. A curative tactic might be the mass-release of large numbers of these enemies, or spraying with a pest-specific bacterial or fungal pathogen. A last-resort curative tactic would be the minimal application of a chemical pesticide, preferably one of the new generation of selective pesticides that is toxic to only a very narrow range of pest species.

IPM has scored some notable successes for pest control in North America, but its role in tropical agriculture is less well known. For this reason, the United Nations Environment Programme (UNEP)—being concerned with conservation of the environment—and the International Centre of Insect Physiology and Ecology (ICIPE)—being mandated to develop environmentally safe pest management strategies—have jointly commissioned a 'global' review of IPM. Special emphasis has been put on assessing the impact of IPM-related activities over the past two decades in the tropical regions of Asia, Africa and South America. Prominent agriculturalists/IPM practitioners were commissioned to take stock of the current status and prospects for IPM in their respective regions and to spell out new paradigms and directions that IPM must take if it is to be adapted on a scope and scale necessary to make a sea change in farmers' and governments' current reliance on chemical pesticides as the accepted agricultural mode.

Woven within the matrix of the three review papers are many pertinent observations and recommendations about the adaption and implementation of IPM region by region. The editors thought it worthwhile to extract these as part of their Executive Summary, in order to make this report more useful for agriculturalists, environmentalists, policy-makers and IPM practitioners. We believe the coverage provided by the authors of this important subject is understandable by a wide cross-section of the public, however, and will be of interest to all of us who share Carson's concern that 'to have risked so much in our efforts to mould nature to our satisfaction and yet to have failed in achieving our goal would indeed be the final irony' (*Silent Spring*, 1962).

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Acronyms and Abbreviations

ABCP	The Africa-Wide Biological Control Programme
ADB	Asian Development Bank, Manila, Philippines
AGRHYMET	Centre Régional de Formation et d'Application en Agrométéorologie et hydrologie Opérationnelle, Niamey, Niger
ANDEF	Associacão Nacional de Defensivos Agricolas
AVRDC	Asian Vegetable Research and Development Centre, Taipei, Taiwan, China
BHC	benzene hexachloride
BPH	brown planthopper (*Nilaparvata lugens*)
Bt	*Bacillus thuringiensis*
CASAFE	Camara de Sanidad Agropecuaria y Fertilizantes
CBC	classical biological control
CEMIP	Centro de Manejo Integrado de Pragas/Universidade do Estado de São Paulo
CGIAR	Consultative Group on International Agricultural Research, Washington DC, USA
CIAT	Centro Internacional de Agricultura Tropical, Cali, Colombia
CICIU	Center for Introduction and Production of Beneficial Insects, Peru
CILSS	Le Comite permanent Interetats de Lutte contre la Secheresse dans le Sahel, Ouagadougou, Burkina Faso
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico DF, Mexico
CIP	International Potato Center, Lima, Peru
CIRAD	Centre de cooperation internationale en recherche agronomique pour le developpement, Paris, France
CNPSO	Centro Nacional de Pesquisa de Soja
COSCA	Collaborative Study of Cassava in Africa, IITA, Ibadan, Nigeria
CTA	Technical Centre for Agricultural and Rural Cooperation, Wageningen, The Netherlands

DANIDA	Danish International Development Agency, Copenhagen, Denmark
DBM	diamondback moth (*Plutella xylostella*)
DDT	III-trichloro-2,2-bis-(*p*-chlorophenyl)thane
ECA	Economic Commission of Africa
EIL	economic injury levels
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation), Brasilia, Brazil
FAO	Food and Agriculture Organization of the United Nations, Rome, Italy
GIFAP	Groupement International des Associations Nationals de Fabricants de Produits Agrochemiques (International Group of National Associations of Manufacturers of Agrochemical Products), Brussels, Belgium
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit, Eshborn, Germany
IARC	International Agricultural Research Centre
IBPGR	International Board for Plant Genetic Resources, Rome, Italy
ICA	Colombian Agricultural Institute, Colombia
ICAR	Indian Council of Agricultural Research, New Delhi, India
ICI	Imperial Chemical Industries, UK
ICIPE	International Centre of Insect Physiology and Ecology, Nairobi, Kenya
ICRAF	International Centre for Research and Extension in Agroforestry, Nairobi, Kenya
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andra Pradesh, India
IFAD	International Fund for Agricultural Development, Rome, Italy
IIBC	International Institute of Biological Control, Silwood Park, UK
IICA	International Institute of Agricultural Sciences (Instituto Interamericano de Cooperación para la Agricultura), San José, Costa Rica
IITA	International Institute of Tropical Agriculture, Ibadan, Nigeria, and Cotonou, Benin

ILCA	International Livestock Centre for Africa, Addis Ababa, Ethiopia
ILRAD	International Laboratory for Research on Animal Diseases, Nairobi, Kenya
INIA	Chilean National Institute for Agricultural Research, Lima, Peru
INIBAP	International Network for the Improvement of Banana and Plantain, Montpellier, France
INSAH	Le CILSS Institut du Sahel, Bamako, Mali
INTA	Argentinean National Institute for Agricultural Technology, Argentina
IOPERM	International Organisation for Pesticide Resistance Management, Bethesda, Maryland, USA
IPA	State of Pernambuco Agricultural Research Enterprise, Brazil
IPC	integrated pest control
IPM	integrated pest management, IRRI, Manilla, Philippines
IPM-R	Integrated Pest Management for Rice Network
IPVM	integrated pest and vector management
IRL	Information Research Ltd, London, UK
IRRI	International Rice Research Institute, Los Banõs, Philippines
IVM	integrated vector management
NAR[E]S	national agricultural research [and extension] systems
NGOs	non-governmental organisations
NPV	nuclear polyhedrosis virus
NRI	National Resources Institute, London, UK
NSKE	neem seed kernel extract
ODA	Overseas Development Administration, London, UK
OPS	Office of Project Support, UNDP, New York, USA
PEG	Pyrethroid Efficacy Group (India), Hyderabad, India
PROCISUR	Cooperative Programme for Agricultural Research in the Southern Cone
RAPA	Regional Office for Asia and Pacific, FAO, Bangkok, Thailand
RENPAP	Regional Network on Pesticides in Asia and Pacific, New Delhi, India
RTV	rice tungro virus

SEMTA	Servicios Multiples de Technologias apropriadas
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme, Nairobi, Kenya
UNIDO	United Nations Industrial Development Organisation
USAID	United States Agency for International Development, Washington, DC, USA
WARDA	West African Rice Development Association, Bouake, Côte d'Ivoire
WHO	World Health Organization, Washington DC, USA

1 Practice of Integrated Pest Management in Tropical and Sub-Tropical Africa: An Overview of Two Decades (1970–1990)

O. ZETHNER
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Integrated pest management (IPM) should be understood to refer not only to the 'integration of all available control methods for a given pest but also to the integration of pest management into the whole farming system and the farmers' economic activities'. Furthermore, IPM should be regarded as 'a strategy and an approach to developing technologies directed towards reducing losses', rather than placing too much emphasis on development or transfer of specific control technologies. This requires on-site research and extension, as well as a government policy which promotes attention to cost-effectiveness and which does not subsidise non-economic or environmentally damaging practices (Kiss and Meerman, 1991).

In other words, 'IPM [should] provide a strategic management approach to pest problems which integrates methods and disciplines with due consideration of environmental values and socio-economic parameters' (Knaussenberger, USAID, pers. comm.).

PROFILE OF AFRICAN FARMING

African agriculture is characterised by a very large majority of small-scale farmers, who cultivate small landholdings of less than one hectare to a few hectares. There are great differences between farms in the various agro-ecological areas. In arid and less fertile areas, landholdings are larger than in the more humid, fertile areas. Small-scale farming not only dominates subsistence agriculture but is also the normal situation in cash crop cultivation. The number of great agricultural estates

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and big landowners is relatively small in Africa as a whole, although the number of absentee landlords is increasing in several countries.

There are also differences with regard to land ownership and tenure. In most countries, farmers do not have title to the land they cultivate, but only the right to farm land which they and their ancestors customarily have cultivated. Often, the ruling of village headmen or local government officials is decisive in questions concerning who has the right to farm a certain piece of land. Although the majority of small-scale farmers control the land they cultivate, some are tenants or share-croppers on lands controlled by others, in particular for cash crops such as cotton. Tenants and share-croppers are, however, far less abundant than is the case in South Asia, for example.

The questions of ownership or rights to farm the land are extremely important when it comes to implementing IPM. Only people who are sure of reaping the fruits of their efforts will be willing to invest the extra work, and sometimes the money, which is necessary for implementing IPM; such investment is needed, for example, for scouting, cultural control, herbicides, etc.

Another problem related to ownership of the harvest is that of the role and status of women. In many countries men are regarded as the legal owners, who can decide over the harvest, even when women have done most of the actual field work. Women, who are overworked anyway, have therefore little incentive to do any extra IPM-related work.

The African crop and pest situation

It is a characteristic of African agriculture that only a few of the cultivated crops are indigenous to Africa. This is the case with millet and sorghum, two of the most important subsistence crops of arid areas, and coffee and cotton. But many of the important crops have been introduced into the continent, some a very long time ago (e.g. rice), some with the European colonisers since the 16th century (e.g. cassava, maize, sweet potato and cocoa), and some more recently (e.g. Irish potato, wheat).

Although some serious pests in Africa are indigenous, such as most pests of millets, sorghum and coffee, there have been a large number of accidental introductions of major pests and diseases from other continents. The pest situation has worsened during the past couple of decades, as illustrated by the introduction of the cassava mealybug, cassava green mite, and larger grain borer. The main reasons for these introductions are increased travel and trade between continents, inefficiently trained and equipped quarantine and plant protection services, and poor infrastructure in Africa.

Many accidentally introduced pests have caused severe damage due to lack of natural enemies. Such situations have stimulated a search for natural enemies of the pests in their countries of origin. It is not a coincidence that classical biological control (CBC) in Africa has met with some successes, as this paper describes in more detail below.

African crops are often cultivated in mixtures (mixed cropping, intercropping). This traditional practice serves several purposes such as ensuring food security, optimal use of the soil and space, maintenance of soil fertility, erosion control, reduction of the need for weeding, and in some cases reduction of the incidence of pests and diseases. In many mixed cropping systems the combined yields are at least as high as in monocultures of each of the crops used. Mixed cropping may, however, have certain disadvantages, for instance when a farmer wants to use herbicides instead of mechanical weeding.

Most farmers in Africa are very poor and the cash they may earn is normally only sufficient to pay for basic necessities (including school fees) and is not enough to invest in cultivation. This fact has to be taken very seriously when attempting to introduce IPM.

Farmers' traditional practices of pest control

In contrast to the editors of a recent World Bank publication on IPM (Kiss and Meerman, 1991), this author has found that many African farmers' knowledge of insect and other animal pests, weeds, and to a lesser degree pathogens, is generally good, even if it may not be based on strictly scientific grounds.

This should not be surprising, because farmers throughout the millennia have practised cultural and mechanical pest control based on trial and error, as part of their land management systems. Through their continuous selection of seed, tolerant or resistant varieties have been promoted. It is therefore important that farmers' experiences always be taken into consideration in planning and implementing pest control projects and other activities.

Traditional control practices are still used by most African farmers in their food crops for home consumption, but only a few attempts have been made to compile details of such practices. One unpublished example is the list of traditional methods of plant protection against the main pests of food crops in the Sahel (Sanou, 1984). The small-scale bean production system in Mgeta, Tanzania, represents a good example of successful traditional practices in one crop and has been described in detail by Mohamed and Teri (1989). Here, farmers use both deliberate and incidental practices to manage insect pests and disease. Choice of growing season and date of planting are observed closely as means to avoid disease. The September–December season with reliable and well-distributed rains, neither too cold nor too humid to favour fungal disease, is best suited for bean cultivation. Planting commences as soon as the rains start because early-planted crops suffer less from insect pests.

Incidental control takes place in the form of cultural practices. By using intercropping with a number of crops, the risk of crop failure is reduced. Terracing, where crop residues and weeds are buried under the soil, reduces the amount of initial inoculum of certain pathogens. Farmers deliberately use a mixture of seeds of different cultivars, some high yielding and early maturing and some late maturing, thus ensuring food early in the season and beans later on as a cash crop. Such a variety of mixtures also appears to provide a buffer against pests and diseases.

The use of chemical control in Africa

The African agricultural scenario is dominated by a large population of small-scale farmers, who mainly practise subsistence agriculture, and a smaller proportion of farmers who mainly cultivate cash crops. The distinction between small-scale subsistence croppers and small-scale cash-croppers is not clear, as smallholders have to sell more and more of their harvest to be able to earn badly needed cash. The use of pesticides by subsistence farmers is limited, due to their relatively high costs and their non-availability in most local markets.

In commercial food crops and industrial crops, chemical control has long since been used abundantly, often resulting in increased short-term yields, but also in increased numbers of cases of human poisoning (WHO, 1990), development of pest resistance to pesticides (FAO, 1967a), water pollution, etc.

In commercial crops, pesticides are the major control agents. These are frequently supplied by organisations such as cooperatives, and are often applied as calendar prophylactic treatments. In such cases, one frequently observes a spillover effect for pesticide application on food crops grown for home consumption. Substantial surplus amounts of insecticides supplied freely by governments and donors for specific purposes, such as for locust and grasshopper control, have similarly spilled over to other uses. In most countries there is an acute shortage of adequately trained plant protection specialists, a lack of well-organised plant protection services and generally poor linkages between agricultural research, extension agents and farmers. This lack of guidance presents severe problems for farmers, in particular when it comes to chemical control.

Many governments still favour subsidising pesticides, which may lead to overuse, in particular when proper extension services are lacking or weak. Certain donor countries add to this problem when supplying large amounts of pesticides as part of an aid packet, without targeting these pesticides properly and without giving enough assistance to ensure their proper use. The seriousness of the situation is illustrated by a survey carried out by the FAO. According to this, fewer than half of the countries in Africa including those north of the Sahara appear to have legislation on pesticides (FAO Plant Protection Services, pers. comm.).

Most countries are not yet able to comply with all the provisions of the 'International Code of Conduct on the Distribution and Use of Pesticides' adopted by the FAO Conference in 1985 (FAO, 1986). This Code is an agreement between member countries and the International Group of National Associations of Manufacturer of Agrochemical Products (GIFAP) on procedures to be followed in relation to import/export, distribution and use of pesticides. The FAO implements several technical assistance projects to strengthen implementation of the Code (Schulten, 1989).

Although pesticide usage is still low in Africa as compared with other continents, there are indications that use is rapidly increasing (WHO, 1990). Based on the few available data, it is postulated that the percentage growth in pesticide use in Africa during the period 1988–93 will have been about 200%, against 40% in Latin America and less than 25% in Asia. The great growth in Africa may to some degree be explained by the use of insecticides against locusts and grasshoppers in the Sahel-Sudan region after 1986. On average, the growth in developing countries was 55% against 20% for the world total. Thus, pesticide usage in Africa in the five years to 1993 appears to have accelerated compared to the period 1983–88 (when it was estimated to increase by 60%), which even then was the highest in the world.

The FAO is not in possession of more exact data, and neither is

GIFAP (GIFAP, pers. comm.). There is apparently an urgent need for statistics on the use of pesticides in Africa, categorised as herbicides, insecticides and fungicides. Such statistics cannot be expected to be very accurate, but should at least be able to indicate trends for pesticide use on the continent.

DEVELOPMENT OF IPM IN AFRICA

According to information from the Plant Protection Services of FAO (Rome and Accra) and the authors of the recent World Bank publication on IPM in African agriculture (Kiss and Meerman, 1991), IPM projects in Africa are few, but work on single IPM components (e.g. on resistant varieties, biological control and training), is continent-wide.

This situation is, to a certain degree, confirmed by the response to a questionnaire sent to all African countries by this author. The few replies which were received added very little to the information published or reported by international organisations, such as the World Bank, FAO, ICIPE, IIBC, NRI, and various agricultural research centres of the CGIAR group. (NB: See List of Acronyms and Abbreviations for full names of these and other abbreviated organisations.)

A list of African IPM projects and other projects which include a major IPM component is shown in Table 1.1. and the Appendix to this chapter. While the list is likely to be complete with regard to proper IPM projects, it certainly does not include all projects and activities which contain IPM components. Comprehensive descriptions in the World Bank publication cover several of the most important projects (Kiss and Meerman, 1991).

Governments and donors pay only scant attention to alternative plant protection measures when agricultural and rural development projects are planned and implemented. One reason may be that applied research results on IPM are still relatively scarce and that many applicable results have yet to be transmitted to the planners in a comprehensible form. In any case, many African governments and some donor countries have yet to perceive the importance of research in development, and only one African country (Sudan) has adopted IPM as the official policy for crop protection (FAO Plant Protection Services, pers. comm.). However, some African growers' societies and corporations do accept IPM as their policy.

Most work on IPM in Africa is carried out in projects funded by international donors. In spite of the considerable research work with relevance to IPM that has already taken place, in particular in international agricultural research centres (IARCs), ready-to-use alternatives to pesticide use are still available to farmers only on a limited scale.

Capacity building in IPM

The personnel available for crop protection and IPM are too few and often inadequately educated and trained. Many African countries have agricultural research institutions staffed with researchers who are often educated in the universities of developed countries. As salaries are relatively low at national institutions, many of the best scientists in Africa join international research organisations or projects, or universities and institutes in developed countries. The research staff remaining at national institutes are often in great need of training, and lack adequate access to scientific literature, equipment for laboratory experiments, and transportation to carry out good work.

Most African countries have an agricultural extension service but only a few are able to make it function effectively, in particular with regard to crop protection; this results in poor training of farmers. Many extension staff become frustrated due to lack of transport, fuel, housing, etc. These shortcomings have been reported in numerous reports and conference papers. Although international organisations, in particular the FAO and the World Bank, and a number of donor countries have for more than a decade been assisting African governments and regional organisations such as CILSS in building up their capacities, these are still far from sufficient with regard to IPM.

A considerable number of staff have received training on improved plant protection in courses sponsored and funded by FAO or donor countries, sometimes in newly established regional departments. One such example is the CILSS Crop Protection Training Department at the AGRHYMET centre in Niamey, Niger, initiated in 1982 (Moussa, 1989).

Other courses take place in the African Regional Post-Graduate Programme in Insect Science (ARPPIS) at ICIPE in Nairobi, Kenya (Dabrowski, 1991a). Special crop protection courses teaching IPM for students from developing countries are also found in a few industrialised countries, for instance at Wageningen Agricultural University, The Netherlands (Huis, 1989).

Table 1.1. IPM and IPM-related projects in Africa

Project no. (see appendix)	Crop	Country/ region	Project	Donor	Year
	Basic food crops				
1.	Millet, sorghum, maize, rice	Sahel	CILSS	Netherlands	1982–
2.	Cowpea	Sahel	CILSS/FAO	USAID	1982–87
3.	Cowpea	Sahel	CILSS	USAID	1987–
4.	Maize, sorghum, cowpea	Africa	ICIPE		
5.	Maize, sorghum cowpea	Kenya	ICIPE	ECA	1988–
6.	Maize, sorghum cowpea	Africa	ICIPE/OPS	UNDP	1988–
7.	Millet	Mali	Government	ODA	1988–
8	Rice	Burkina Faso	Government	Netherlands	1985–
9.	Rice	Madagascar	Government	Switzerland	1984–
10.	Maize	Africa	IITA/ICIPE	Many	
11.	Maize	E Africa	NRI	ODA	1989–
12.	Millet	Sahel	ICRISAT	Many	
13.	Sorghum	Sahel/E Africa	ICRISAT/ICIPE	Many	
14.	Sorghum/millet	Africa	USA	USA	1979–
15.	Agr. crops	Africa	ICI	USA	1982–
16.	Cereals	Africa	NRI	ODA	1988–
17.	Food crops	Cameroon, CAF, Chad	FAO	FAO	1991–
18.	Basic food crops	Gambia	FAO	UNDP	1988–
19.	Food crops	Cameroon	FAO	UNDP	1991–
20.	Food crops	Africa	GTZ	GFR	1988–
21.	Food crops	Africa	Netherlands	EEC	1989–
22.	Cereals	Somalia	GTZ	GFR	1985–
23.	Staple crops	Cameroon	GTZ	GFR	1991–
24.	Food crops	Africa	FAO	UNDP	1987–
25.	Grain legumes	Ghana	Government	USAID	
26.	Cowpea	Niger	Univ. Tours, France	EEC	1990–

Sources: Compendium of Projects on Plant Protection, FAO, Rome, 8th issue, July 1991, and individual project reports.

Phases					Components					Training			
Planning	Research	Development	Farmers' active involvement	Coordination, organization	Resistance breeding	Biol. control nat. enemies	Chemical control	Scouting/ monitoring	Cultural control	Researchers	Extension staff	Farmers	Project no. (see appendix)
				•							•		1.
	•	•	•	•		•	•	•	•	•	•		2.
				•						•			3.
				•						•	•		4.
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•													25.
	•					•							26.

Table 1.1 (*continued*)

Project no. (see appendix)	Crop	Country/region	Project	Donor	Year
27.	Cassava	Africa	IITA	Many	
28.	Cassava	Africa	IITA	Many	
29.	Cassava	Nigeria	IITA	Switzerland	1983–
30.	Cassava	Africa	GTZ	GFR	1984–
31.	Root crops	Africa	IITA	USA	1982–
32.	Sweet potato	Kenya	Government	CIP/IIBC	1989–
33.	Stored products	Africa	IITA/FAO	Many	
34.	Stored products	Kenya	GTZ	GFR	1987–
35.	Crops incl. stored	Malawi	GTZ	GFR	1990–
36.	Stored grains	Tanzania	FAO	Canada	1988–
37.	Crops	Cape Verde Is.	GTZ	GFR	1977–
	Fruit trees				
38.	Mango	Togo	Government	GTZ/IIBC	1987–
39.	Mango	Gabon	FAO	FAO	1991–
40.	Fruit trees	Congo	FAO	FAO	1990–
41.	Banana	Kenya, Tanzania	ICIPE	GTZ	1989–
42.	Citrus	Egypt	Government	USA	
43.	Coconut	Tanzania	ODA/GTZ		
	Beverage crops				
44.	Coffee	Kenya	Government		
45.	Cocoa	Ghana			1972(?)
	Industrial crops				
46.	Cotton	Sudan	FAO/Govt	Netherlands	1979–
47.	Cotton	Zimbabwe	Government		
48.	Cotton	Togo	Government		
49.	Cotton	Egypt	NRI/FAO	ODA	
	General				
50.		Kenya	FAO	Netherlands	
51.		Egypt	GTZ	Germany	1992

Sources: Compendium of Projects on Plant Protection, FAO, Rome, 8th issue, July 1991, and individual project reports.

Phases					Components								
										Training			
Planning	Research	Development	Farmers' active involvement	Coordination, organization	Resistance breeding	Biol. control nat. enemies	Chemical control	Scouting, monitoring	Cultural control	Researchers	Extension staff	Farmers	Project no. (see appendix)
	●	●		●		●	●	●		●	●	●	27.
	●				●					●	●		28.
						●							29.
													30.
	●												31.
	●	●				●				●			32.
	●	●		●		●	●			●	●		33.
	●	●		●		●	●						34.
		●											35.
	●	●					●			●	●		36.
	●	●		●		●				●	●		37.
		●	●			●	●	●			●		38.
						●							39.
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	●	●				●			●		●		41.
●													42.
	●	●				●	●						43.
		●	●			●	●	●		●	●	●	44.
	●					●	●	●	●				45.
	●	●	●			●	●	●	●	●	●	●	46.
		●	●				●				●	●	47.
		●	●				●				●	●	48.
	●					●							49.
		●		●							●		50.
●											●		51.

Information networks on IPM

The lack of appropriate information is a severe constraint to development and implementation of IPM. Books and other literature are scarce not only in research institutes but also in most African universities and institutions. Many organisations have indicated the need for establishing a network for IPM in the tropics. Such a network would serve to publish bibliographies relevant to IPM, organise literature searches, and function as a liaison between staff working in different countries (Huis, 1989). A commendable contribution has been made by Wageningen Agricultural University who have compiled a worldwide inventory of IPM training and extension materials for tropical food crops, published in 1989 as a catalogue (Alebeek, 1989). Regional networks in Africa such as The African Pest Management and Research Network (PESTNET), which serve 14 eastern and southern African countries, seem a sensible approach especially because of language difficulties. PESTNET performs several of the networking functions above.

PESTNET is devoted to meeting the needs of pest management research, mainly in East Africa (Omolo, 1989). In these countries ICIPE scientists are collaborating with national colleagues in conducting surveys to determine the major economic pests and diseases of maize, and work has begun in some countries to determine which IPM components can be developed as long-term pest management strategies. Studies on banana pests have started in Kenya, Tanzania and Rwanda. Training of national crop protection staff including scientists and technicians is an important part of PESTNET.

Other networks exist between many of the IARCs (e.g. IITA, WARDA) and national agricultural research and extension systems (NARES) in their respective research areas. It is important that the mesh between the strands of the net are sufficiently narrow to embrace all major agro-ecological zones in a region or country. At present, many NARES face difficulties in having enough well-trained staff to participate fully in networking activities, such as in local trials with resistant varieties and in work on biological control agents.

USAID has continued to support some IPM activities under the INSAHs (Institut du Sahel) Pest Management Technical Coordinating Unit, based in Bamako, Mali. Since 1987 this unit has tried to fine tune a collaborative relationship with the national research and crop protection services and international organisations in the CILSS countries in four main areas:

- Sahelian network for research on IPM of crop pests;
- strengthening of crop protection services;
- information dissemination; through scientific and popular books and journals
- regional coordination.

More efforts are required to establish sufficient training facilities and materials, and to educate teachers in IPM. The need for informing governments and donors is urgent, as otherwise over-reliance on chemical pest control will become more and more common in Africa.

TECHNICAL AND BIOLOGICAL COMPONENTS OF IPM

In broad outline, IPM in Africa can be used in two different situations:

- in food crops where little or no chemical control has been previously used, and
- in commercial food crops and industrial crops where an overuse of chemical control has taken place.

Use of resistant varieties

Breeding of resistant varieties is taking place for all major crops. Apart from the crops selected for case studies in this paper, maize deserves special mention. The research at IITA resulting in the breeding of varieties resistant to the maize streak virus, abundant in large parts of Africa and transmitted by cicadellids, offers farmers significant yield increases (IITA, 1986). ICIPE, among others, has bred maize varieties resistant to stemborers (ICIPE, 1991b).

Another example is an IPM project using sweet potato varieties resistant to nematodes and weevils, which is to be undertaken by CIP in Kenya, Rwanda and Burundi (CIP, 1992).

The international research institutes, which breed varieties resistant to major insect/mite pests and diseases for all agro-ecological zones, are indeed doing an impressive job. This work will probably never finish because new situations constantly require new varieties as new virulent strains and races of disease organisms and pests develop. Breeding of varieties that are resistant to more than one pest, and at the same time are high yielding, is a great challenge to researchers.

Constraints or weak points to the practical use of resistant varieties are found in the African NARES, which normally lack sufficient manpower, knowledge and facilities. The utility of good research work depends both on government and donor support, and here individual government officials' motivation and understanding of the problems are essential. These same considerations are also valid for biological control (see below).

The work of the International Board for Plant Genetic Resources (IBPGR) and CGIAR institutes in collecting landraces and wild relatives of crops and in conserving germplasm, forms an important basis for research and development of resistant and tolerant varieties (IBPGR, 1992).

Cultural control measures

Cultural control includes many measures, some based on more general principles, others specific to the crop, soil, locality, socio-economic environment and other conditions.

Crop rotation and fallow

These cultural methods have been used over most of Africa for centuries. Both methods reduce the risk of accumulating pests from year to year and reduce the general level of insects, diseases and weeds.

Rotation is being used in places that are not dominated by a single crop (monoculture). It is still possible to maintain rotation over large parts of Africa, in particular in subsistence cultures. However, to keep fields fallow in a production system has become increasingly difficult because of the great population pressure all over Africa and the decreasing fertility of soils, which forces farmers to cultivate the same areas year after year, rather than to let them rest. In many places farmers simply do not have sufficient productive land to cultivate, as soils have been exhausted and have not been given enough manure or fertilizers as compensation.

Projects aimed at making lands more fertile and allowing increased fallow will also contribute indirectly to IPM. A soil rich in nutrients will give a healthy crop which is capable of resisting attacks by insects and diseases and which can compete better with weeds.

Intercropping

Traditional systems of intercropping various crops are common in Africa. Two examples are sorghum with cowpea in West Africa and maize with beans in East Africa. Overall, scientists have come to the conclusion that intercropping has an influence on the population build-up of insect pests. Studies by several researchers have revealed that intercropping reduces the incidence of pests in cases where the crops used in intercropping are not hosting the same insect species. In contrast, intercropping of crops that host the same insect pests increases the incidence of those pests.

The reduction of pest incidence with intercropping of non-host plants may partly be explained by the increased diversity of the agro-ecosystem combined with changes in the microclimate of the field. Other factors such as different planting times for the crops are also important.

Weeding

Weeds represent one of the most severe constraints to optimal yields, often causing greater losses than other pests. Losses caused by uncontrolled weed growth vary between 28% and 100%, depending on the crops and cropping systems (Adegoroye *et al.*, 1989). The significance of weeds is easily overlooked because, unlike with most insects and diseases, weeds can substantially reduce yields without obvious signs of damage (Terry, 1983). Serious weeds in Africa represent a number of families, e.g. Gramineae (annual and perennial grasses), Cyperaceae, Euphorbiaceae and Scrophulariaceae. The latter include parasitic plants (the witchweeds *Striga* and other genera), which feed on roots and which have become increasingly important in arid zones of Africa.

Weed control takes more time than any other single agricultural occupation, ranging from 20% to more than 50% of total labour time (Adegoroye *et al.*, 1989). Practically all weeding of subsistence crops is done manually and it requires much labour to complete the two to three weedings necessary in most crops. Because of the lack of labour on farms during peak cultivation periods, weeding can often not be accomplished as it should. A qualified guess is that at least 25% of most subsistence crops in Africa are lost due to inadequate weeding; in particular, lack of early weeding and lack of weeding within plant rows is costly.

The use of herbicides is becoming more prevalent in African agriculture, not only among large-scale cash crop growers who have used chemicals for some time, but also among small-scale farmers, who neither have the labour nor the money to pay labour for manual weeding.

There is much research and development to do before weed control can become an integral part of IPM, because weed control remains one of the most underexploited practices for improving crop production in Africa (Terry, 1983). Few countries on the continent employ adequate staff for research, extension and training in weed control. Also, international interest in weed control in the developing countries appears to be limited, as is indicated by the staff composition of crop protection projects and agencies.

Mechanical control

Some insect pests can be crushed on the plants or collected and destroyed afterwards, as for example with locusts and caterpillars. Such methods may be used effectively in gardens or even in large fields, when properly organised. For instance the eggs of *Heliocoverpa (Heliothis)* are crushed on cotton in Egypt (ICI, UK, pers. comm.).

Biological control

Classical biological control

Classical biological control (CBC) means the deliberate introduction of exotic biological control agents for long-term depression and regulation of pest populations. The cumulative achievements of CBC have been impressive, even in Africa. The International Institute of Biological Control, UK (IIBC), has been the major organisation involved in CBC, including selection and screening of host-specific agents against economically important arthropod and weed pest species (Waage and Greathead 1988).

Until 1988, almost all of the biological agents introduced were arthropods (insects and mites), but a small number of pathogens (fungi, bacteria and viruses) had also been used. Worldwide, substantial successes were reported in 40% of 421 introductions against insect pests and in 31% of 113 introductions against weeds. Using pathogens, there were only four successes against insect pests and two against weeds (Waage and Greathead 1988).

In Africa, the greatest success has been the introduction of a parasitoid against the cassava mealybug, as described in the case study on cassava. Great CBC successes have been achieved against other serious insect pests introduced accidentally into East Africa: citrus black fly, *Aleurocanthus woglumi*; apple woolly aphid, *Eriosoma lanigerum*; eucalyptus weevil, *Gonipterus scutellatus*; jacaranda bug, *Orthezia insignis*; coffee mealybug, *Planococcus kenyae* (Cock and Greathead, 1991).

Mauritius presents a unique case in that all pests of sugarcane, a crop which covers 90% of all cultivated land, are controlled biologically (Fachnath, 1989). Insecticides are not used. Mauritius is the first country on record to have successfully introduced a natural enemy, namely the minah bird, to combat the red locust, *Nomadacris septemfasciata*, in 1792. The most severe pests include some species which are also important pests in other parts of Africa: the sugarcane stemborer, *Chilo sacchariphagus*; armoured scale, *Aulacaspis tegalensis*; white grub, *Heteronychus licas*; soft scale, *Pulvinaria iceyi*; armyworm, *Leucania loreyi*; and the pink borer, *Sesamia calamistis*. Besides CBC with parasitoids and predators, control includes the use of resistant cane varieties and sex pheromones. Sugarcane insect pests have also been successfully controlled in other parts of Africa, such as *A. tegalensis* in Tanzania.

Recent examples of CBC programmes in Africa in which IIBC takes part comprise the control of banana pests in Kenya, stored products in Kenya, and mango in Togo. Some results from mango are described in detail by Meerman (1991b). The programme in Togo is directed against the mango mealybug, *Rastrococcus invadens*, originating from South Asia, which was accidentally introduced into Togo in 1981, where it spread quickly, probably even to neighbouring countries. The Indian IIBC station began a survey for the pest and its natural enemies, and found a parasitoid (*Gyranusoidea* sp.), which was proven to be specific to the mango mealybug. In late 1987 and early 1988 specimens of this parasitoid were officially introduced, mass-propagated and released in five different locations.

By using a simple and cheap monitoring method the Togolese Plant Protection Service was able to show that the parasitoid had spread throughout the distribution area of mango mealybug in Togo. During a survey tour of practically all of Togo it was not possible to observe a single mango tree that did not have both mealybug and parasitoid populations. A cost–benefit analysis revealed that the economic viability of the programme would already be established if only slightly more than 1% of the economic loss by the mealybug had been prevented over a period of four years. In fact, much greater losses have been prevented, without any cost to the farmers.

Inoculation, augmentation and inundation

These are other forms of biological control which have not reached much beyond the research stage in Africa (Waage and Greathead, 1988). Inundation (mass-scale rearing and release) of *Trichogramma* parasitoids is begin tested in the integrated cotton project in The Sudan against *Helicoverpa* and in ICIPE's project in Kenya against *Chilo* (ICIPE, 1991b).

In coconut plantations in East and West Africa, species of a plant-sucking bug (*Pseudotheraptus*) cause heavy nut losses of 30–65%. Palms occupied by thriving colonies of a predatory ant (*Oecophylla* spp.) are almost completely protected from damage by the pest (Way and Khoo, 1992). Unfortunately, relatively few plantations are well colonised by *Oecophylla* because other dominant, non-beneficial competing ant species have displaced them. In Cote d'Ivoire an IPM programme has been established in which insecticides are used to control the pest and competing ant species as a supplement to biological control. This includes artificial introductions of *O. longinoda* on palms where the beneficial ant is absent, and encouragement of a diversified scrub and ground vegetation that favours beneficial ant species. Insecticide treatment is only used on trees which are not colonised by the beneficial ant. It is reported that damage becomes insignificant in this control system (Fataye and de Taffin, 1989).

Liberating natural enemies formerly suppressed by chemical control

For various reasons there seems to be a strong inclination to overuse pesticides in cash crops, as described in this paper under the case studies on coffee, cotton and mango. This frequently leads to a situation where populations of natural enemies are reduced and therefore lose their normal ability to control the pests. In the case studies mentioned, and in a number of other situations, it has been shown that reducing the number of sprays or even abandoning spraying with insecticides altogether results in almost the same or sometimes even better economic benefits to the grower.

Chemical control

Treatment of seeds with fungicides is a normal part of most IPM programmes. It is a cost-effective measure which does minimal harm to the environment, provided the appropriate chemicals are used.

Most chemical control in Africa is carried out against pests of industrial and other crops which earn the growers enough cash to enable them to buy the pesticides for further treatments. Many treatments are so-called calendar treatments, executed on dates which are predetermined by a plant protection service or by consultants for pesticide companies without much regard to the actual pest situation at the time. Such a routine system is the easiest to handle for everybody, but is expensive in terms of pesticides; furthermore, it gives inadequate protection against the pest, and causes high mortality of the pest's natural enemies.

A realistic alternative to calendar spraying is spraying based on data on the size of the pest population, and determination of the threshold level above which it is economical to spray. Such threshold-level determinations have been essential for reducing or abolishing spraying in the case studies on coffee, cotton and rice pests. For farmers, reduction of spraying means a saving on the costs of pesticides, prices of which are rapidly increasing.

Monitoring methods are essential in order to measure pest and natural enemy populations and population trends. Such methods may include scouting, trapping and other methods which can be learned and used by farmers. Training of farmers and extension service personnel in using such methods is, in fact, one of the most important parts of IPM.

Training is also extremely important for correct handling of pesticides. WHO reports that the annual number of cases of unintentional acute poisoning with pesticides worldwide was half a million in 1972 but had increased to one million in 1985. The increase has been at the same rate as the estimated increase in the world consumption of pesticides (WHO, 1990).

Although manufacturers of pesticides are aware of the shortcomings and side-effects of broad-spectrum pesticides, many still continue to produce and sell such products to African countries. And, many donor countries continue donating broad-spectrum pesticides. New research is, however, aimed at developing more selective pesticides which can be used without too many side-effects on the beneficial fauna and flora

(Sechser, 1989). The situation in cotton, described in the case study, is an example.

One example of a selective pesticide is the newly developed Pymetrozine. This product belongs to a new insecticidal group (pyridine azomethine) and is used primarily against sucking pests such as whiteflies and aphids. Field sensitivity trials were done in a number of crops including cotton, in Egypt; the pesticide was demonstrated to be harmless to three representative predator species of aphids (ladybird beetles, flower bugs and green lacewings). Pymetrozine may replace Pirimicarb as a leading product against aphids in cases where the latter product encounters resistance problems (CIBA, Geigy, pers. comm.).

Several chemical companies have recently changed their interests towards the production of microbiological control agents, especially strains of *Bacillus thuringiensis (Bt)*. This bacterium is being marketed in Zambia, Sudan and Morocco, while entomopathogenic fungi and viruses are being marketed in Zimbabwe. One may foresee this tendency expanding in the near future (Sechser, 1989).

IPM FOR MULTIPLE CROPPING SYSTEMS

In basic food crops cultivated by subsistence farmers, IPM should be regarded as part of an overall programme which addresses basic constraints hampering agricultural production. In such cases IPM often becomes one component of farmers' overall activity to improve yields and income that is difficult to separate from other components. Projects of this kind might not be called 'integrated pest management' but rather, 'integrated crop management' projects (Schulten, 1989) or 'integrated land management' projects (Zethner, 1991), where the objective is to increase agricultural production and farmers' income using IPM as the strategy for pest control.

There are only a few examples of projects directed to IPM of multiple cropping systems as a whole. The best known are the CILSS/FAO project for basic food crops in the Sahel funded by USAID (1980–87), and the ICIPE project for multiple food crops in Western Kenya, funded by the Economic Commission for Africa (1988–92). Both projects included or were based on heavy inputs from research and extension services. These projects deserve a more detailed description as much can be learned about the prospects and constraints when attempting to introduce modern IPM into African subsistence agriculture. In the two examples cited, IPM has been implemented with little or no chemical control component.

The CILSS/FAO project in the Sahel

The project 'Research and Development of Integrated Pest Management for Basic Food Crops in Sahelian Countries' (FAO, 1987) lasted four to six years in most countries, and received a total funding of nearly US$ 30 million, almost exclusively from USAID. The original timetable for the project, which was well planned by IPM specialists from American universities, comprised three phases of five years each, which would have allowed for a necessary, sufficient gestation period between commencement of graduate training and the productive research years of the individual African researcher (Nwanze, 1991b). Unfortunately, the project was terminated after the first phase.

The project succeeded, however, together with another USAID-funded CILSS project on Regional Food Crop Protection, in building up small research teams and relevant research institutions and facilities in each of the CILSS countries, which were at the time Burkina Faso, Cape Verde, Gambia, Mali, Mauritania, Niger, Senegal and Chad. Very valuable research was carried out on a number of problems caused by pests which had hardly been investigated before. A considerable number of extension staff received on-the-job training in IPM (FAO, 1987).

Unfortunately, adequate IPM technologies could not be developed and extended to farmers during the short time-frame available. Thus, the donor failed to recognise that it takes time to obtain valid results from research—in Africa as anywhere in the world! However, it is interesting to note that people trained under the CILSS projects are reported by USAID to have had considerable impact on pest management in Senegal, Mali and Burkina Faso. Also, researchers trained under the project were used effectively during the grasshopper and locust campaigns in 1987–89.

Important research results were obtained by joint international and national teams for pests of millet, sorghum, maize, rice and cowpea (FAO, 1987). For example, our knowledge of witchweed (*Striga* spp.) on cereals and leguminous crops, spike borer and blister beetles of pearl millet, and fungal diseases of rice in the Sahel is far greater than before the start of the IPM project. But many problems were left unfinished, such as the joint programme of monitoring key pests by systematic countings in observation fields all over the Sahel, which, if combined with climatological data from AGRHYMET (Centre Régional de Formation et d'Application en Agrométéorologie et hydrologie Opérationelle, Niamey, Niger), could have provided basic information for the establishment of forecasting systems.

Millet

During the final two to three years of the IPM project certain efforts were made to extend research results in millet to farmers through pilot programmes (FAO, 1987). These were mainly cultural measures to reduce losses and improve certain agronomic practices to increase yields: seed treatment, thinning, early destruction of plants infected with downy mildew, removal of *Striga* before flowering, application of fertilisers within crop rows and certain country-specific pest control measures. However, because of the lack of effective control measures against some of the most important pests (millet spike borer, stemborers, blister beetles, downy mildew, birds) farmers did not adopt the pilot programmes wholeheartedly.

The IPM pilot programmes demonstrated that substantial average yield increases of 58% to 80% could be obtained by using improved agricultural practices including cultural control methods (FAO, 1987). Except in specific cases it was not possible to distinguish between yield increases due to generally improved agricultural practices and control methods against pests. In Mauritania, yields were compared with the minimum yield per hectare which should be harvested in order to obtain self-sufficiency in each area. In 1985 the pilot programme averaged 91% to 145% of this minimum yield as compared with 50% to 84% in farmers' traditional cultures. Although it was not possible to make a general economic analysis, it was possible to show that certain interventions (e.g. removal of *Striga*, weeding in plant rows, use of improved millet varieties) were cost effective. More information about millet IPM is found in the next section of this chapter.

Lessons learned

Socio-economic investigations showed a number of constraints which severely hampered adoption of IPM measures by the farmers (FAO, 1987). The major agronomic constraint was undoubtedly lack of proper control methods against major pests, without which farmers hesitate to continue IPM on their own. The shortage of farmhands to carry out timely weeding and removal of *Striga* also posed serious constraints. (There are limits to how much work overburdened African women can accomplish.)

Government promotion of chemical control measures simultaneously with the integrated pest management project in the Sahel counteracted the project's success. Availability of subsidised insecticides made it difficult to convince farmers of the advantages of IPM (Zethner, 1991).

Important economic constraints to the adoption of IPM were and continue to be the lack of investment in smallholder agriculture, thereby hampering the conversion of subsistence agriculture into more productive agricultural systems which can create cash earnings. The rapidly decreasing fertility of African soils, in particular in arid zones, contributes to these constraints. Incentives in the form of free supply of fertilisers assisted the implementation of the IPM pilot programmes, but may not have promoted IPM in the long term, as farmers tend to lose initiative if they become used to receiving incentives.

The ICIPE IPM project in western Kenya

Another example of a large-scale multicrop IPM project was carried out in Kenya: 'Integrated Pest Management of Crop Borers for Resource-Poor Farmers in Africa' (ICIPE, 1991b). This project was based on ICIPE's long-term research work and was funded by a number of donors. The food crops included sorghum, maize and cowpea. Stemborers (*Busseola fusca*, *Chilo partellus*, *Sesamia calamistis* and *Eldana saccharina*) in sorghum and maize, the pod borer, *Maruca testulalis*, in cowpea, and the sorghum shootfly, *Atherigona soccata*, cause important losses in these crops which are further increased by post-harvest losses due to flour beetle, maize weevil and grain moth. The programme involved three stages:

Basic research on IPM components Cultural practices include intercropping sorghum–cowpea which was found to reduce oviposition of *C. partellus*, thereby reducing damage. Intercropping maize with sorghum, however, increases damage by stemborers. Early planting reduces damage by stemborers and sorghum shootfly. Disposal of crop residues prevents survival of diapausing stemborers.

ICIPE research has also resulted in a number of resistant, good-yielding varieties and cultivars of sorghum, maize and cowpea. Furthermore, indigenous parasitoids and pathogens have been effectively controlled at the experimental level, and an improved trapping system for stemborers has been developed for behavioural manipulation.

Multi-site testing of promising components This has been done in on-station fields under ICIPE management. Biological control and behavioural components are still under multi-site trials.

Pilot trials Those components which have proven promising have been tried under farmers' management and ICIPE supervision. Intercropping of maize, sorghum and cowpea, other cultural practices, and host-plant resistance have been used.

From 1986 to 1990, a joint ECA/ICIPE project entitled 'Reduction of Food Losses through Insect Pest Management and Use of Small-Scale and Low-Cost Farm Equipment in Africa' has been executed by ICIPE in collaboration with Kenya's Ministry of Agriculture. Fifty farmers in the Kendu Bay and Oyugis Divisions of South Nyanza District participated in the project. The Ministry of Agriculture seconded seven extension staff members, who were trained at ICIPE in both the agronomic and pest control aspects of cereal and legume growing.

Training of farmers played an important role in the form of two-way communication between extension workers and farmers, and through short three-day-long training courses, as well as through farmer–scientist communication. Besides technical advice, farmers were provided with improved seed of resistant, good-yielding varieties, and with incentives in the form of fertilisers, farm implements, construction materials for improved granaries, and tractor ploughing.

The results indicate that yields have improved considerably. Although it is impossible to distinguish between improvements due to better pest control and improvements due to better crop husbandry practices, it appears that the latter contribute more than the former. Many farmers in the area probably consider agronomic problems such as *Striga hermonthica* and post-harvest losses more important than stemborer damage, which is not very severe in South Nyanza.

It was reported that many farmers produced a surplus which can be sold for cash in the local markets, allowing them to buy, for instance, animals for ploughing and hire labour for weeding. A final evaluation of the impact of the project had not been carried out at the time of writing this paper, but there are indications that farmers may continue constructing granaries, renting ploughs and using other techniques which have helped to increase the yields.

Comparison between IPM conditions in the Sahel and western Kenya

There seems to be little difference between the basic constraints facing farmers in Kenya and the Sahel. In both cases, it was only possible to provide technical answers to some of the pest problems, and not to the most important ones. Poverty and labour shortages during the growing season were common to both areas.

The apparent modest success of the IPM project at the farming level in Kenya, and the lesser success in the Sahelian countries, may be partly explained by the differences in farming conditions and the farming communities themselves.

Sahelian farmers grow their crops on relatively light soils and with little rainfall, and can only grow one crop per year. In the Oyugis area of Kenya, soils are good and there are two rainy seasons, thus allowing for two crops per year. Western Kenya is far more densely populated than most Sahelian countries, which results in shorter distances to market places and stimulates more communication and trade.

The extension inputs and incentives given in Kenya exceeded those given in the Sahel; these may actually counteract sustainability unless the population sees an urgent need for continuing on its own. It is possible, though, that the population in Oyugis has created enough surplus to allow it to continue without further incentives.

It is important that the projects be evaluated a few years after their termination to determine which interventions have been sustainable and which have not. Also, any spill-over effect to communities not involved in project activities should be investigated. Such post-project evaluations are unfortunately very rare, although they would seem extremely relevant.

IPM FOR PEARL MILLET IN THE SAHEL

Pearl millet (*Pennisetum typhoides*) has been cultivated for thousands of years in Africa, and was probably introduced into in West Africa south of the Sahara. The plant is cultivated in most semi-arid areas, but most abundantly in the Sahel–Sudan regions, were millet constitutes the basic food for a large part of the population. Generally millet surpasses other cereals with regard to utilisation of nutrients from poor soils, and shows great salt- and pH-tolerance. It is normally cultivated under conditions of 400 to 500 mm annual rainfall, but is an important crop even at lower levels.

In spite of its widespread distribution and importance, pearl millet has not been the subject of breeding until recent years, as for example by ICRISAT in India and Niger. Testing and selection of breeding materials under highly variable conditions for cultivation makes it possible to create tolerant, higher yielding varieties with maximal stability.

Pearl millet is cultivated both in monocultures and in mixtures with other crops such as sorghum, leguminous plants, or with *Acacia albida* as shade trees. Intercropping increases with decreasing precipitation. Crop rotation is normal as seen in the millet–groundnut systems in the Sahel or in the millet–*Acacia senegal* system. Fallow periods, which formerly were a normal part of traditional millet cultivation over the centuries, have been shortened drastically as a result of food demands by increasing populations.

There exists a great variety of cultivation techniques. Pearl millet may be sown in rows or broadcast; sometimes ridge-sowing takes place. Simple hand tools or small-scale mechanical equipment may be used, the latter with oxen or donkeys.

Major pests (CILSS, 1986)

Although pearl millet is relatively tolerant of weed competition, weeds do perhaps pose the most severe pest problem over the entire millet cultivation area, particularly during drought conditions. The parasitic witchweed *Striga hermonthica* is becoming increasingly important.

The stemborer complex, *Chilo* spp. in East Africa, and *Sesamia calamistis* and *Coniesta* (*Acigona*) *ignefusalis* in West Africa, is present in most millet fields, and the last-mentioned species, in particular, causes heavy damage. Grasshoppers and armyworms (*Spodoptera* spp.) may be quite serious defoliators, especially of young millet plants. After the drought periods in the Sahel which began in the late 1960s, the millet spike borer, *Heliocheilus* (*Raghuva*) *albipuctella*, became a pest of considerable importance, and in certain geographical areas blister beetles (meloids of the genus *Psalydolytta*) cause havoc by sucking grains in the milky stage, often destroying total millet fields.

Of the various pest groups attacking the spike, granivorous birds (*Ploceus*, *Passer*, *Quelea*) are the most damaging. *Tolyposporium penicillariae* converts grain into green, then later dark brown, smut sori. Downy mildew caused by the fungus *Sclerospora graminicola* causes stunted growth and deformed chlorotic leaves and tillers. In cases of heavy attack, it destroys the spike.

IPM experience

Sufficient knowledge exists to recommend a tentative IPM programme for Sahelian conditions (FAO, 1987).

Breeding for resistance

Millet varieties with tolerance or some resistance to birds, insect pests or diseases must be selected. Work on breeding resistant varieties against stemborers, spike borer and downy mildew was intensified at ICRISAT (Gahukar *et al.*, 1986) and varieties resistant to downy mildew may be developed in the near future (ICRISAT, 1992). On the other hand, one cannot expect early results from stemborers and spike borer (Nwanze, 1991a).

Special attention needs to be given to varieties with long bristles on the spike that give some protection against birds and blister beetles. In the Gambia, a long-bristled variety (*Souna bado laebi*) yielded the same as the normally used non-bristled landrace during years without many pest problems. *Souna bado laebi* showed distinctly more resistance to birds, spike borer and blister beetles, and yielded some grain even after heavy attack by blister beetles and locusts, whereas non-bristled varieties yielded nothing (Zethner *et al.*, 1990).

Cultural control

Crop rotation is a hygienic measure against pests and helps in retaining soil fertility. In the Sahel, millet is often rotated with groundnuts.

Removal of plant debris after the previous harvest will reduce the risk of fungus and stemborer attack in the next season. Millet stalks used for fencing can be heated before use to kill stemborer larvae overwintering inside the stems.

Seeds must be treated with a fungicide. Early sowing is generally recommended, especially where great risk of blister beetle attack exists. Machine-sowing in rows does facilitate weedings later on. Fertilisers should be applied close to rows and not in the middle of rows, to benefit the crop and not the weeds.

Weedings must be done within rows first, and thereafter between rows. Studies show that Gambian farmers lost more than 25% of the potential crop yield by weeding between rows first, and thereafter neglecting weeding in rows. Similarly, mechanical or chemical weeding of young *Striga* plants reduces losses substantially. The weed must be totally uprooted/killed before flowering, as the very small seeds can survive in the soil for more than 10 years, thus causing constant new infestations of millet plants (Carson, 1986; Zethner, 1987). Plants infected with downy mildew and stemborers must be removed at an early stage in order to reduce the risk of later infections of the spike.

Cultural methods that reduce carryover populations of *Coniesta* and *Heliocheilus* should be exploited, and sociological and organisational problems associated with their implementation should also receive attention equal to that of technical problems (Nwanze, 1991b).

Chemical and other direct methods for insects

Five years of field trials in Mali (three years of low and two years of high rainfall) have shown how production and pest damage vary with rainfall. Thus, equal populations of *Heliocheilus* caused less damage in wetter years due to the plants' greater ability to compensate (Jago, 1991). Addition of phosphorus fertilizer or the use of a resistant variety resulted in much higher yields than the use of chemical insecticides.

While chemical control of the spike borer may be uneconomic and should not be promoted, chemical control of blister beetles and locust might be necessary to protect the crop against total destruction. The decision whether to use chemical control in millet may depend on the determination of estimated threshold levels at different points during the season, including light trapping and other survey methods (Jago, 1991).

ICRISAT and ODA have cooperated to synthesise a highly efficient pheromone blend of *Coniesta ignefusalis*, and have developed a trap which can be operated by farmers. The trap may be used in the direct control of stemborers, but is immediately useful in large-scale monitoring and for population studies (ICRISAT, 1992).

Farmers' traditional control with fires in the field, the smoke of which deters blister beetles from the spikes, in particular when groundnut shells are burned, has been shown to be efficient in the Gambia (Zethner and Laurense, 1988). This practice, however, may take up too much of farmers' time at night to be acceptable when farmers have now learned that 'medicines' such as carbaryl and triclorphon are effective.

Biological control

Research on the biological control of millet pests was started in the CILSS IPM project in the Sahel. Surveys revealed the presence of a number of natural enemies that might become important biological agents. Perhaps the most important enemy of *Heliocheilus* is the parasitoid wasp, *Bracon hebetor*, which is very abundant during the latter part of the growing season, as indicated by the high percentages of parasitism (Gahukar *et al.*, 1986). *Bracon* is also found parasitising the larvae of *Ephestia* sp., a pest of millet grain in village storerooms. This is useful, as *Bracon* can survive on *Ephestia* as long as there is millet in the store and is ready to attack larvae of *Heliocheilus* at the right time. Infested *Ephestia* released in larger numbers in Senegalese millet fields gave promising initial results, but this biological control method needs to be tried on a larger scale (Bhatnagar, 1987).

Constraints

IPM activities should become a part of farmers' normal cultivation procedures, but it is a problem to find the extra time during planting, weeding and harvesting. Labour shortages in such peak periods may be one of the main constraints to introducing IPM in the Sahel. Shortage of cash is an obstacle to costly inputs, so IPM measures must be very cheap.

The organisation of the various IPM measures available in millet cultivation is still in its infancy, as the research teams and extension services in Sahelian countries as a whole are too sparse and inexperienced. When more applicable research results for important pests (*Striga*, blister beetles, stemborers, spike borer) become available, the farmers will be more highly motivated to use IPM in their daily management, and governments will be more attracted to supporting research and extension of IPM.

SORGHUM IPM

Sorghum (*Sorghum bicolor*) originated in Africa, where it is still widely grown in semi-arid areas. Sorghum has a range of pests rather similar to those of pearl millet (CILSS, 1986). It is more susceptible to weeds than is millet, especially under drought conditions. The sorghum varieties normally used are more susceptible to *Striga hermonthica* than any other cereal grown in the Sahel.

In the Sahel one finds four main insect pest groups besides many less-economically important pests: sorghum shootfly, *Atherigona soccota*, and other species causing deadheart; the stemborer complex including *Busseola fusca*, *Sesamia* sp., *Chilo diffusilineus*, and others; sorghum gall midge, *Contarinia sorghicola*, causing improper formation of the spikelets; and sorghum headbug, *Eurystylus* sp., sucking on developing grains.

Smut fungi remain the most important sorghum pathogens in the Sahel, destroying the grains, but grain moulds are on the increase.

IPM recommendations

These are still incomplete due to lack of research results. ICRISAT has developed sorghum varieties with broad-spectrum resistance against *Striga*, but these may not be stable under very high pressure (Carson, 1986). Research on shootfly has had a breakthrough (ICRISAT, 1992), but there is a long way to go until resistant varieties are ready. Some differences are found between varieties with regard to headbugs (ICRISAT, 1991). The work done at ICIPE in East Africa shows promise for breeding of resistant varieties against various stemborer species which are also present in West Africa (ICIPE, 1991a).

Cultural control should follow the recommendations for pearl millet, with extra emphasis on removal of *Striga*, and the destruction of crop residues and diseased plants. Chemical control is generally not recommended, except for seed treatment with fungicides against smut, and herbicides for the control of *Striga*, in the case of a shortage of labour.

CASSAVA-BASED IPM

The following general description of cassava cultivation in Africa is compiled from several references (Hahn *et al.*, 1979; Terry, 1983; Hill and Waller, 1988). Cassava (*Manihot esculenta*) was introduced from South America to Africa by the Portuguese, probably in the last part of the 16th century. The rapid spread of the crop on the continent may be attributed to its adaptability to the social framework of the farming community. It can be grown with limited inputs and requires few production skills. Cassava has a long growing cycle, from nine months to two years, and planting and harvesting are not seasonal. The tubers can be kept in the ground for up to 24 months and harvested when required for consumption.

Cassava is now widely cultivated in tropical Africa, from humid to semi-arid regions. The crop is relatively drought tolerant and can survive even four to six months of dry weather. It can also produce relatively well at low nutrient levels. Since its introduction, cassava has played a vital role in alleviating famine conditions by providing a sustained food supply when other crops have failed.

It was estimated in 1980 that more than one-third of the calorific input in African diets was met by cassava tubers, and that young leaves are a preferred vegetable in many tropical regions. During the last 30 years, cassava production in Africa has increased at the same rate as the population growth, mainly due to an increase of new land planted while yields per hectare have remained at the same low levels (5–8 t/ha).

Cultivation

Cassava is commonly intercropped by smallholder farmers in Africa, the pattern depending on environmental conditions and food preferences of the region, but large-scale commercial farming also exists. The long duration of cassava cropping is suitable for intercropping with shorter duration crops since the two types of crops attain their full development at different periods. Several studies have shown that land productivity is higher under intercropping with maize and cowpea than under monocropping. More research work is required to study the relationship between cassava and other crops in intercropping systems and to determine the highest yielding associations.

Cassava is normally grown on ridges which must be preserved during weeding operations. Weeds should be controlled until a good crop canopy has been formed (Terry, 1983).

Major pests

Cassava in Africa has been relatively free of arthropod pests as compared with cassava in its place of origin, South America. This is probably because of its status as an exotic plant in Africa, and because of its high content of cyanogenic glycocides and latex (Herren and Neuenschwander, 1991). Two accidentally introduced pests, the cassava mealybug and cassava green mite, both avoiding this chemical defence, have become the most severe pests of the crop in an amazingly short time.

Mealybug, *Phenacoccus manihoti*, was introduced accidentally from a rather restricted area in South America into Central Africa where it was first reported in Zaire in 1973. The pest spread mainly by air across the cassava-growing areas at a speed of 300 km per year, until it now occurs in 32 countries in all agro-ecological zones. The cassava mealybug rapidly became the major pest of cassava, stunting the growth points and sometimes totally defoliating the plants. The mealybug poses a tremendous threat to cassava farmers as losses of more than 80% of the tuber yields have been reported (Herren and Neuenschwander, 1991).

Cassava green mite, *Mononychellus tanajoa*, was also introduced from South America first into Uganda (1971) and later to most of the cassava-growing belt in Africa, by air and infested plant parts. Attacked leaves are deformed and develop a mottled, bronzed, mosaic-like appearance, ending in necrosis of stem and leaves from top to bottom. The green mite is regarded as a less serious pest than is the mealybug, but may still cause severe yield losses of tubers in susceptible cassava varieties (Herren and Neuenschwander, 1991).

African cassava mosaic virus is transmitted by whitefly, *Bemisia tabaci*, and perhaps other insect vectors, and can be transmitted over several kilometres by the insects. The virus is also carried in cuttings of infected plants. The disease may cause tuber losses of 20–60% (Hahn *et al.*, 1979, 1990). Bacterial blight caused mainly by *Xanthomonas campestris* pv. *manihotis*, natural to Africa, has been reported in many countries throughout the continent. The disease may result in complete yield loss under conditions favourable for its development and spread. Movement of infected planting materials and rain-splash are most important for spreading the disease (Hahn *et al.*, 1990).

Classical biological control

Effective control of cassava mealybug soon became almost a prerequisite for cultivation of cassava in many countries. An IITA workshop in 1977 concluded that classical biological control and resistance breeding against the mealybug were feasible control strategies to adopt, and urged IITA to begin a research programme. A biological control programme commenced in 1979 and had, 10 years later, grown into what is probably the world's largest biological control programme, supported by many international donors and collaborating with several other international research organisations including IIBC and CIAT.

The basic strategy of the biological control programme was to search for predators and parasitoids of the cassava mealybug in its native habitats in South America. The mealybug was found in Paraguay in 1980 by a CIAT entomologist, and during the following year a joint IIBC and CIAT mission collected 10 species of natural enemies, among these the parasitoid wasp *Epidinocarsis lopezi*, which was considered to constitute the effective complex that keeps in check populations of mealybug in its original South American habitats.

Predators and parasitoids were rigorously screened at IIBC in the UK to ascertain their specificity for the mealybug and to assess any possible problem that could arise if they were to be introduced into Africa. The natural enemies were mass-reared at IITA in Nigeria, and their suitability as predators and parasitoids was determined. Ground and aerial releases of the most suitable species were followed by monitoring surveys to determine whether or not the enemies had become established and how effectively they controlled the cassava mealybug. The results were amazing. Three years after the first release, one of the parasitoids (*E. lopezi*) was found in 70% of all cassava fields in more than 200 000 km^2 in southern Nigeria, showing one of the highest dispersal rates known for species of Microhymenoptera (Herren and Neuenschwander, 1991).

In 1985 this programme was expanded into the Africa-Wide Biological Control Programme (ABCP) (Herren, 1990; Kiss, 1991a) to implement the positive and promising research results in all regions of the cassava belt suffering from serious pest problems. A sponsoring group under the auspices of IFAD in collaboration with many donors supports the ABCP. By 1990 *E. lopezi* had become established in 25 of the countries where cassava is cultivated.

The biological control of cassava mealybug has proven not only ecologically but also economically sound as seen in the benefit/cost ratio of 178 to 1 for the mealybug work, representing a return of over US$ 20 million over a project period of almost 20 years from the time the mealybug was discovered in Zaire. The major reason for the high ratio is that biological control is a self-sustaining strategy and requires only a single low-cost input. The organisational aspects were also cost effective, as the programme used an integrated problem-solving approach via research, training and development of national biological control programmes and facilities in 19 countries.

Establishment of these national facilities is important as there are strong indications that the original stock of the parasitoid derived from the IITA centre in Benin will not provide sufficient protection in all countries when released (Münster-Swendsen, Univ. of Copenhagen, pers. comm.). There is a need for different ecological races which are adapted to the areas where mass-release will take place. Such races should be collected fairly soon after the release of the original stock, as the parasitoid adapts itself to the new environment fairly quickly after release. The adapted race should then be mass-reared by the national programme.

Work on cassava green mite has so far yielded far fewer prominent results. A number of potential predators have been introduced and released but no efficient biological control agent has yet been found. Recently, attention has focused on predatory phytosetid mites of the family Phytiseeidae, which are able to sustain control at lower prey densities than most insect predators.

Breeding resistant varieties

Even before the mealybug and green mite were found in Africa, researchers in Nigeria succeeded in breeding varieties resistant to the African cassava mosaic virus. One such 'old' resistant clone (No. 58308) has been crossed with local cultivars and even with another cassava species. The selected resulting clones and families have continued to show resistance to the virus under different environmental conditions throughout Africa for at least 10 years. The progress with resistance breeding against bacterial blight has been much slower, and has not reached the stage where the results can be applied (Hahn *et al.*, 1990).

Sources for resistance against cassava mealybug and green mite have been identified from IITA breeding materials. Resistance to both pests is significantly associated with the density of hairs on the upper and lower leaf surfaces, petioles and young stem tips. One variety, TMS4(2)1425 has performed outstandingly well over locations and years, yielding on average 21 t/ha. This resistance can be utilised by genetically incorporating the pubescence character into even higher yielding but susceptible varieties.

Surveys carried out since 1989 in humid areas by the Collaborative Study of Cassava in Africa (COSCA) have revealed that small-scale cassava growers actively experiment with new varieties by abandoning old varieties when they prove unsuitable and adopting new, more suitable ones (IITA, 1990). It was also found that where new varieties had been widely disseminated (by IITA in Nigeria) about 90% of the villages surveyed used the new varieties. It is essential that new resistant varieties are acceptable to the growers with regard to taste, and that any change of cultivation necessary to maximise yields of the new variety (i.e. planting density, fertiliser levels) is communicated to farmers.

Cultural control

Improvement of cultural practices may, at least indirectly, lead to better control of pests of cassava. Selection of healthy vegetative planting material is of utmost importance, in particular with regard to virus and bacterial diseases. Cuttings from the basal stem sections from 12–18 month-old plants give faster growth and highest yields. High yields also require a large supply of nutrients in the form of mulch or chemical fertilizer, and even no-tillage systems can result in significant yield improvements. More vigorous growth will enable the plants to recover better from insect attack (Hahn *et al.*, 1979).

Although the optimum time of planting to maximise tuber yield varies from one ecological zone to another, it has been shown that the length of growing season has a significant effect on crop yield. Thus in Ghana, planting of cassava at the beginning of the rains gave significantly higher yields than delayed planting. Whether or not planting time has an influence on attack by pests is not well documented. Intercropping may reduce the risk of insect or mite infestation as the cassava plants are separated by other crops on which the pests do not feed. However, data confirming this are not available.

The most important pest-related cultural activity is weeding, which commonly is very time consuming as cassava is normally weeded two or three times per growing season (Terry, 1983). The timing of the first weeding is most important as a delay of two weeks has been shown to reduce the yield by 20%. An integrated weeding management system may combine hoeing with low-growing intercrops like melon, or with low rates of pre-emergence herbicides for early weed control in rapidly branching cultivars that readily shade the ground. Such a low herbicide input level may be affordable even for the small-scale farming family which does not have enough hands available during the rainy season.

RICE IPM, WITH SPECIAL REFERENCE TO BURKINA FASO AND MADAGASCAR

Rice (*Oryza sativa*) is cultivated in most parts of Africa, either under rainfed or irrigated conditions and under different cultivation patterns according to the various ecological conditions under which rice is grown, e.g. dryland, swamp areas or irrigation. The majority of the cultivators are small-scale farmers. Rice has become an increasingly important crop, probably as a result of a change in attitudes and eating habits, particularly in countries which have received large amounts of rice as food aid during periods of drought or other emergencies.

Although the rice pest complex varies over the continent, some serious pest types are found in practically all rice-growing areas (Hill and Waller, 1988). Lepidopteran stemborers belonging to the genera *Maliarpha* and *Chilo*, rice blast, *Pyricularia oryza* and weeds comprise the most important pests all over Africa. The pest complex also includes species of bugs, gall midges, leafmining beetles, caseworms and armyworms, in addition to a number of occasionally serious diseases caused by fungi and bacteria (brown spot, sheath blight and bacterial leaf blight disease). Crabs are serious pests in mangrove swamp rice in West Africa.

Two well-defined projects aimed at introducing IPM in rice in Africa will be described here: a programme on 'Rational Pest Control in Irrigated Rice in Vallee du Kou, Burkina Faso', supported by the Dutch government since 1985 (Meerman, 1991a), and a project on 'IPM in Irrigated Rice in the Lac Alaotra Basin, Madagascar' supported by Switzerland since 1984 (Zahner, 1991).

Burkina Faso

The rice area in Vallée du Kou accounts for 25% of the total rice area in Burkina Faso. This scheme was started in the 1970s with Chinese assistance. The initial high yields dropped dramatically in 1983 due to disintegration of both the irrigation system and the small-scale farmer's cooperative, and because of low soil fertility. The new programme has restored yields to high levels by reorganisation of the cooperative, rehabilitation of the irrigation system, recovery of soil fertility, and by development and implementation of IPM components, as described below.

The 'old' rice variety, which was susceptible to a new physiological race of rice blast, was replaced with a resistant rice variety. Such varieties have been developed by WARDA and other research institutes (WARDA, 1990). Cultural control was implemented by specific weeding of *Echinocloa* spp., which are alternate hosts of stemborers (*Chilo* spp.). Farmers were fined if they did not remove this weed. In order to prevent build-up of pest and disease organisms, synchronised sowing and transplanting was done. Drainage of the field for three days effectively controlled floating larvae of the rice caseworm, *Nymphula depunctalis*, which cannot survive without water.

Chemical control against insect pests had formerly consisted of a calendar programme of two to three applications per season (pyrethroids were made available through the cooperative). This system was clearly inappropriate as pest attacks vary greatly between seasons, and moreover the health hazards are high because irrigation water is used for human consumption and fishing. Furthermore, farmers disapproved of being automatically charged for the two to three applications whether or not they had used them.

A rational stemborer control programme was developed based on phytosanitary monitoring and thresholds, with weekly scouting conducted by trained farmers. With this threshold system, insecticide use could be reduced to half of the earlier levels, resulting not only in savings of inputs (money) but even net profit increases of around 10% in 1987/88. The farmers were highly motivated to participate in the new system.

The preliminary result of the IPM part of the project is that a fully farmer-operated monitoring and threshold system has been established, carried out by farmers trained through their cooperative. There are fewer incidences of pests and diseases in Vallée du Kou than in other irrigated rice schemes because of adequate crop management including weeding and synchronisation of planting dates.

In West Africa as a whole, WARDA programmes are promoting research in various rice cultivation systems (WARDA, 1988, 1990). Repeated tillage integrated with herbicide application, and in some cases supplemented by manual weeding, has eliminated problems with *Euphorbia heterophylla*, one of the most difficult weeds to control in upland rice. Problems with annual (but not perennial) weeds in irrigated systems may be greatly reduced as a side-effect of the free-floating aquatic pteridophyte *Azolla*, used as a supplier of nitrogen; the layer of *Azolla* reduces light necessary for weed growth.

WARDA research teams are also developing IPM packages in a programme that includes breeding resistant varieties, and testing new cultural, biological and chemical measures to combat blast, stemborers and crabs, the last-mentioned in mangrove systems (WARDA 1988, 1989).

Madagascar

In the Lac Alaotra Basin project, which covers an area of 60 000 ha cultivated by smallholders, the Malagasy government wanted to increase rice production by reducing losses estimated at about 30% due to the white rice stemborer, *Maliarpha seperatella*. Control by chemical aerial spray application was done in 1982/83 but was stopped when it was found that fundamental basic information was lacking in order to evaluate the appropriateness and overall efficiency of the application. It was feared that the purely chemical approach could threaten the ecology of the rice agro-ecosystem. A joint R&D project aimed at clarifying the economic importance of rice pests and at identifying future alternatives was therefore initiated (Zahner, 1991).

Research revealed that mechanical or chemical control of weeds, which had previously been neglected, could increase yields by 20% on average. Adequacy of irrigation was a prerequisite for farmers before investing in weed control.

With regard to stemborer control, it was shown that chemical intervention could not be justified economically, as it was impossible to find an insecticide that was both effective and acceptable from a toxicological and environmental viewpoint. The stemborer larva does not destroy the sap-conducting tissue and is therefore difficult to kill. For the time being, the government has to accept a loss not exceeding 30%, and has stopped providing free pesticide applications for stemborer control. Farmers have not shown interest in investing in such control on their own.

The monitoring of stemborer populations which started in 1982/83 has been refined and developed into a full-scale pest monitoring and scouting system implemented by teams from the plant protection service, at no cost to the farmers. Because it is recognised that scouting responsibilities must be transferred to the farmers, a training programme has been offered simultaneously. As such training takes a long time, it is envisaged that the protection team will continue to operate for some time.

Institutional problems such as poor communication between the two ministries involved and difficulties in reconciling the interests of farmers and those of political leaders have been severe. While politicians are interested in higher rice production to meet the growing demand of the urban sector, the farmers prefer recommendations which leave them time for other activities such as fishing and livestock husbandry that provide them better returns. It may therefore not be easy to convince farmers to scout their fields.

The other important insect pest, the hispid beetle *Hispa gestroy*, which defoliates leaves, did not cause significant losses below a certain threshold, due to plant compensation of leaf production, and higher beetle population densities were seldom reached in the fields. After the insecticide applications were stopped, it was seen that parasites of the rice hispid recovered from earlier low levels. It was therefore recommended that chemical control of the hispid should take place only in rice nurseries, where the plants are vulnerable and where natural enemies do not have the time to build up. In the field, hispid control should be left to the indigenous natural enemies. If it is proven that the hispid is a vector of a new rice disease, these recommendations may be modified.

The main result of this IPM project has been to demonstrate the critical importance of achieving a basic understanding of the agroecosystem, rather than immediately launching a chemical control programme. By following this approach it may be possible to avoid the devastating development of secondary pest species which plague irrigated rice production in many other parts of the world.

COTTON-BASED IPM WITH SPECIAL REFERENCE TO THE SUDAN

Cotton (*Gossypium* spp.) is cultivated in most parts of Africa as one of the major cash crops on the continent, and in the Sudan, Egypt and Zimbabwe, cotton is a very important export crop. The cultivation can take place on many soil types as long as they are not too sandy or clayey. Cotton in Africa is grown by small-scale and large-scale farmers, but small-scale farmers are in charge of the majority of lint production in most countries. In the Sudan, cotton has been grown under irrigation since 1867 and increased substantially in Gezira after the completion of the Sennar Dam in 1925 (El Amin and Amin, 1991).

Among all crops worldwide, cotton has the most insect pests. From germination to harvest, the cotton plant is exposed to attack from numerous weeds, insect pests and diseases, which in many instances are the major obstacles to optimal yield. Yield losses in Sudan have been estimated to range between 40% and 65% (El Amin and Amin, 1991).

Young cotton is severely affected by delayed or inadequate weeding, and is particularly susceptible to weed competition when soil fertility and moisture are low (Terry, 1983). Four or five weedings are required before the crop produces a canopy. The use of herbicides is becoming more frequent in cotton, as mechanical weeding requires human labour or draught animals.

The major insect pests of cotton in the Sudan are whitefly, *Bemisia tabaci*; the cotton bollworm, *Helicoverpa (Heliothis) armigera*; jassid, *Empoasca lybica*; and aphids, *Aphis gossypii*. Important diseases are wilt, caused by *Fusarium oxysporium*, and bacterial blight, caused by *Xanthomonas malvacearum*. These pests are also present in most other cotton-growing areas in Africa. The case study presented below is an example of an IPM programme in which there has been overuse of chemical control.

History of cotton pests in the Sudan

The history of cotton and its pests in the Sudan is educative and ecologically interesting (El Amin and Amin, 1991). Until the mid-1940s the jassid was the only economically important pest present and a number of other insect pests (thrips, termites, cotton stainer, pink bollworm and stemborer) and some diseases were controlled with various cultural practices and legislative control methods.

The system was gradually changed from a three-crop to an eight-crop rotation to stop the build-up of bacterial blight. Regulations required tenants to uproot and burn cotton residues, not to grow ratoon cotton and to use closed seasons on some vegetable crops, in order to control bacterial blight, leaf curl virus and pink and spiny bollworms. Also, varieties resistant to bacterial blight and leaf curl virus, and a hairy-leaf variety resistant to jassid (but unfortunately susceptible to whitefly), were introduced.

During the same period some other cultural practices aggravated the pest situation (Kiss, 1991b). Cultivation of cotton had expanded into more humid areas where pest problems are more severe. Planting of groundnut and sorghum had become more common and this, together with the introduction of early-fruiting cotton varieties, had resulted in higher populations of bollworm in the early part of the season. Introduction of fertilisers and new varieties which responded vigorously to the fertilisers resulted in increased attack by whitefly. Elimination of fodder crops from the rotation (one of which served as a useful trap crop for bollworm) led to irrigation late in the season, thereby causing an extension of the growing season which has benefited the pests. Enforcement of closed seasons and phytosanitary measures slackened, and due to the current system of crop rotation, pest populations can now build up around the year.

Failure of chemical control

From the mid-1940s chemical control (starting with DDT) became the practice and yields did not in fact initially increase substantially. However, later on the continued use of modern insecticides did not bring about corresponding increases in yields. Yield and spraying statistics in the Sudan Gezira Scheme date back to 1925 (El Amin and Amin, 1991). Comparing 20-year periods, it is notable that cotton yields have not increased more than 15% on average over a 60-year period. From 1945 until 1987, the number of sprays per year had increased by six to nine times, with a consequent increase of the cost of spraying until it became equivalent to about 25% of the total production costs.

Although economic threshold levels for key pests had been used since the 1950s, and scouting teams to monitor populations had been established early on (El Amin and Amin, 1991; Kiss, 1991b), the system had serious weaknesses. Thus, the threshold remained the same over several decades resulting in spraying at lower pest densities than necessary.

Since the mid-1960s, the expansion of cultivated areas together with the diversification of crops and intensification of rotations have caused major changes in the insect pest complex. By the end of the 1960s, whitefly had become a season-long pest which occurred each year, and which was more important than either jassids or bollworms. Since then whitefly has remained the most serious cotton pest in the Sudan, partly because of its direct negative impact on yields, and partly also because the aphid excretes a honeydew that makes the lint sticky and decreases its market value by up to 20%. Whitefly is difficult to control as it feeds on the sheltered underside of leaves. In the past few years aphids have also become important pests by contributing to the honeydew problem.

An important factor for cotton cultivation in the Sudan was the 'package deal' system in which pesticide manufacturers were contracted to control cotton pests on a guaranteed yield basis at a fixed price per unit area (Kiss, 1991b). This system succeeded in increasing production through 1978, but was abolished in 1981, perhaps because of the fact that whitefly populations were higher in areas taking part in the package deal system than in areas outside the system.

The IPM project

The spraying of chemicals over so many years had a serious negative impact on the populations of natural enemies. While 140 beneficial insect species were reported in the 1920s, only 40 such species were found in cotton fields in the mid-1980s (Abdelrahman and Munir, 1989). As a result of the decrease in returns in spite of the ever-increasing use of insecticides, the cost of which could not be afforded by the Sudanese state, a project, 'Development and Implementation of Integrated Pest Control for Cotton and Rotational Food Crops in the Sudan' was started in 1979. The project was executed by FAO in partnership with the IPM Unit of the Agricultural Research Cooperation Department, Sudan, and funded by the Netherlands. This project, now in its third phase, has gained much useful experience, not only for IPM in cotton but also in other crops where overuse of chemical control has taken place (Abdelrahman and Munir, 1989; Schulten, 1989).

Initially the project created awareness about the need for IPM, and carried out research on the development of whitefly-resistant varieties and population dynamics of pests. It was soon realised, however, that too much emphasis was being laid on research in relatively small plots. Therefore, in the second phase it was agreed that comparisons should be made between 100-acre sprayed and unsprayed plots (for a total of 330 ha).

Unsprayed trials

The results showed that yields of the unsprayed area were 10% to 20% less than those of the sprayed area, but that this loss of yield was largely compensated for by the savings obtained by not spraying. In addition, the lint of the unsprayed area was 100% stickiness-free, because natural biological control had kept whitefly and aphid populations at acceptable levels. The populations of insect pests and natural enemies were closely monitored. In 1989, millions of *Trichogramma praetiorum* were released to test their effectiveness against *Helicoverpa*.

In the present third phase, large-scale experiments and demonstrations have continued. Threshold levels of major pests are continually re-assessed, and spraying schemes developed to be applied only when needed. Cultural and biological control methods are used as much as possible, and only 'milder' chemicals are used when absolutely necessary. It is considered important that control measures be coordinated so that they take place simultaneously in the same area. More selective insecticides and the more selective use of broad-spectrum insecticides are being tried which, together with rotation of insecticides of different classes, may counteract the build-up of new pests and resistance in the insect pests currently present. The search for biological control alternatives such as more potent strains of *Bacillus thuringiensis* and *Baculovirus* (NPV) has also been strengthened (Sechser, 1989).

Resistant varieties

New varieties of cotton with high resistance to whiteflies have been bred, and should be used more abundantly.

Cultural control

Apart from great reductions in insecticide application and use of resistant cotton varieties, cultural control methods are still going to play an important role in cotton IPM. Some of these methods used before the era of insecticides and some of newer date are mentioned below.

Deep ploughing can bury or expose resting stages of *Helicoverpa* and other insect pests to unfavourable environmental conditions. Proper systematic watering can kill pupae of *Helicoverpa* and other pests by oxygen deficiency. By choosing a proper sowing time, cotton might escape from infestation with some pests. If cotton fields and their surroundings are freed of weeds, there is less risk of infestation than in badly weeded fields, because many weeds are known to be hosts of cotton pests.

Balanced application of fertiliser may increase the compensatory ability of plants to overcome damage caused by pests. However, excessive use of fertiliser promotes outbreaks of sucking pests and should be avoided. A renewal of crop rotation including clean-fallow could reduce outbreaks of *Helicoverpa* and *Bemisia*. The use of trap plants such as *Hibiscus esculensis* in the vicinity of cotton fields is known to reduce flea beetle attack on cotton seedlings.

Organisational issues

The major constraints to IPM in cotton in the Sudan are found in management issues. For the Agricultural Production Corporation there is a greater motivation for increasing yields than for cost reduction, as their contract with the government is to produce a certain yield within a certain budget (Kiss, 1991b). Yield increase is also the main performance criterion for the crop protection field staff and is the basis on which the cotton-producing tenants are paid. Because the costs of pesticides are deducted from their accounts along with other inputs, they do not know how much they are paying for pest control. Therefore, tenants do not directly appreciate the value of cultural practices that will reduce pest damage, but may believe instead that a reduction of cotton yields will deprive them of fodder for their livestock, and at a higher labour input from their side.

The IPM cotton project in the Sudan has opened some avenues for overcoming these difficulties by collaborating with the tenants in the large-scale field experiments and in having meetings with the Tenants' Unions, in which one agreed to provide a compensation guarantee fund. Tenants are showing interest in the new approach. These ideas are supported by the World Bank in the context of its agricultural lending programme and policy dialogue in the Sudan.

Training of researchers, field staff and farmers has been an important part of the project. The use of large-scale trials has meant a much closer cooperation with field staff and farmers than would have been the case if one had followed the original objective of having the strategy developed by researchers and then extended by a competent extension staff.

This adjusted project approach has had the great advantage that all concerned have been involved with IPM from the very beginning: farmers, field staff, researchers and administrators. The result has been that interest and confidence in IPM in the Sudan is increasing, and that the Sudan is the only country in Africa where IPM has been adopted as the official policy for pest control.

Cotton IPM in other countries

Zimbabwe and Togo are facing problems with cotton similar to the ones in the Sudan, but solutions are slower in coming than has been the case in the Sudan, where cotton has been the major export crop for such a long time (Kiss and Meerman, 1991). An approach to IPM is gradually being built up in commercial farms in Zimbabwe. Here, monitoring and scouting of pests are basically as in the Sudan, but there is not yet a true integration of chemical with biological and cultural control. Small-scale farmers are not benefiting from existing knowledge, and their needs in relation to chemical control and scouting are now being addressed by research.

In Togo almost all farmers are smallholders who suffer from inadequate crop husbandry practices, poor and variable soil conditions, and lack of time for weeding. However, research has resulted in reducing insecticide use with considerable savings for farmers. *Baculovirus* (NPV) mixed with weak doses of pyrethroids has given interesting results. Efforts to promote collaboration between cotton protection researchers are supported by the World Bank.

COFFEE IPM WITH SPECIAL REFERENCE TO KENYA

Coffee (*Coffee robusta* and *C. arabica*) in Kenya is grown by smallholders with average plots of 0.5 ha (70% of the production) and on estates ranging from 4 ha to over 500 ha in size. The smallholders are organised in cooperatives, and also grow food crops for their own consumption. There are great differences between the yields in estates (870–1500 kg/ha) and those of smallholders (average 600 kg/ha), though more advanced farmers in both sectors may reach considerably higher yields (Meerman, 1991c). Yield-limiting factors include inadequate canopy management, low fertiliser use, and improper control of insect pests and diseases.

There are some 30 known species of coffee insect pests in Kenya, the most important being leafminers (*Leucoptera* spp.), several species of bugs and scales (such as fried egg scale, *Aspiridiotus* sp., and soft green scale, *Coccus alpinus*), defoliators and thrips. Since 1980 a previously rare indigenous scale (*Icerya pattersoni*) has attained pest status on large coffee farms in central Kenya.

The major coffee diseases are coffee berry disease caused by *Colletotrichum coffeanum*, attacking ripening berries, and coffee leaf rust, caused by *Hemilea vastatrix*, resulting in premature leaf fall and reduction of the number of flowers (Meerman, 1991c). Another important disease is bacterial blight of coffee (*Pseudomonas syringae*). Smallholders apply much less fungicide than recommended by the Coffee Research Foundation to control berry disease and leaf rust and their method of application is not correct. On the other hand, smallholders apply two to three times more broad-spectrum insecticides than recommended, thus causing secondary pest outbreaks.

Biological control

Although outbreaks of *Icerya pattersoni* are not pesticide-induced, but are more likely linked to the changing irrigation and fertiliser regimes, it was found that insecticide applications exacerbated the situation. Ecological studies and a trial release of a natural enemy, the coccinelid *Rodolia iceryae*, have demonstrated that natural enemies are capable of bringing the pest under control in areas where the populations of natural enemies have been decimated by insecticide use (IIBC, pers. comm.).

The coffee mealybug, *Planococcus kenyae*, was accidentally introduced from Uganda into Kenya in the early 1920s, and has been successfully controlled with two parasitoids from Uganda. These introductions saved the Kenyan coffee industry about £10 million during the period 1935–58, and permitted smallholder farmers to resume growing coffee after a lapse caused by the pest. The fact that the parasitoids came from a neighbouring country within Africa gives rise to hopes for future successful biological control of major indigenous pests in Africa (Cock and Greathead, pers. comm.).

IPM recommendations

The Kenya Coffee Research Foundation recommends an IPM approach, as follows (Meerman, 1991c): A high-yielding coffee variety (Ruiru 11) developed by the Foundation possesses high levels of resistance against coffee berry disease and leaf rust, but seems to have a limited seed production. Therefore new high-yielding resistant varieties are required.

Cultural practices

These include pruning to reduce humidity and thereby the risk of coffee berry disease. Pruning also prevents the antesia bugs, *Ante-*

stiopsis spp., from hiding in leaf clusters. Mulching prevents thrips from reaching the soil for pupation but does, on the other hand, allow leafminers to pupate and thereby increases incidence of these pests.

Spraying

Farmers use different spraying practices. Some, in particular in the estate sector, use no insecticides at all, resulting in adequate control by natural enemies except for short-lived outbreaks of leafminers. Others, both advanced small-scale and large-scale farmers, spray according to threshold levels recommended by the Foundation.

Some farmers do not distinguish between pests and beneficial insects, and therefore spray against natural enemies, while others (small estates and cooperatives) do not use the threshold levels and spray much more than is recommended. Still others, mainly on large estates, tolerate only very little insect damage. The overuse of insecticides leads to secondary pest outbreaks, and is an increasing economic burden on the growers due to doubling of the price of pesticides.

The recommended threshold levels for both insect pests and diseases should be revised, and proper training materials prepared for all categories of farmers, but in particular for smallholders in the cooperative sector who grow two-thirds of Kenya's coffee.

IPM IN COCOA WITH SPECIAL REFERENCE TO GHANA

Cocoa (*Theobroma cacao*) originated in the Brazilian Andes, and was introduced into West Africa in the 17th century (Hill and Waller, 1988). Ghana and Nigeria are among the main production areas in the world, but considerable production is also found in other African countries, e.g. Côte d'Ivoire. Cocoa is a small tree which, in Africa, is cultivated in openings of the natural forest, mostly by small-scale farmers.

The single most important group of insect pests attacking cocoa in West Africa are the capsid complex of bugs (family Miridae), causing lesions on fruits and young shoots, which are then invaded by secondary fungal infection. Other serious insect pests are mealybugs, in particular citrus mealybug, *Planococcus citre*, one of the vectors of swollen shoot virus. Mealybugs have a complex relationship with ants, of which some species are beneficial as they kill the mealybugs, while others are harmful by attending the pest. Other important pests are cocoa stemborer, larvae of a cossid moth (*Eulophontus myrmeleon*), and black pod disease caused by the fungi *Phytophthora* spp. (Entwistle, 1985; Hill and Waller, 1988).

Phytosanitary measures and chemical control are the only means of control, the former mostly against diseases and the latter mainly against capsid bugs. Cocoa varieties resistant to swollen shoot virus exist (Hill and Waller, 1988). IPM is not yet being applied in West Africa (FAO; USAID; P.F. Entwistle, Oxford; P. Amaro, Lisbon, pers. comms.). There is, however, great potential for using beneficial ants as biological control agents.

An elaborate IPM system was proposed by Majer as early as 1974. He showed the enormous role played by dominant ant species which constitute nearly 90% of the total cocoa fauna biomass. The ants are distributed in a mosaic-like pattern in which the distribution of one dominant species does not overlap the distribution of another species. Some species occur in dense cocoa canopies, while others prefer broken canopies. The amount of dead wood and other vegetation and the humidity are other factors important for distribution of ants. An understanding of the factors and mechanisms for maintaining the structure of the ant mosaic is essential if ant manipulation is to form part of an integrated control scheme.

Some ant species, for instance *Crematogaster* and *Pheidole*, tend the mealybugs, thereby spreading swollen shoot virus, and also assist in spreading black pod disease. Other ant species, such as *Oecophylla* and *Macromischoides*, largely protect cocoa from these diseases by preying on pests or driving away pests such as capsid bugs, beetles and lepidopterous larvae. The integrated control approach is to simulate in the perennial cocoa system the key elements of the equivalent ecosystem that benefit the preferred ant species. Thus, the success of ants such as *Oecophylla* primarily depends on creating conditions that are unfavourable for open-habitat, invasive ant species such as *Crematogaster*, which otherwise would almost invariably dominate.

A proposed IPM menu

Majer (1974) proposed an IPM strategy as follows: Within an area to be cultivated with cocoa, all forest trees should be felled and all dead vegetation removed. This is done to remove all potential nesting places for *Crematogaster*. Cocoa thrives best under light shade from taller trees (coconut, citrus, soursop, and others). Coconut is particularly compatible with cocoa. Rows of coconut in and around the peripheries of the cleared area should be planted two to three years before underplanting with cocoa. The periphery planting of coconut hampers the invasion of *Cremagaster* from neighbouring bush or forest lands and encourages *Oecophylla* colonisation. It is important that the cocoa farmland is adequately shaded and has a complete canopy. A broken canopy destroys the habitats of beneficial ants and attracts cocoa capsids.

Maintenance of the farm consists of routine checks (scouting), annual clearing of dead wood and vegetation, and spraying where necessary. Scouting for capsid damage and beneficial ants takes place between August and February, and trees with such ant populations are marked. Unmarked trees with capsid damage are sprayed with insecticides. Scouting for *Crematogaster* nests is done throughout the year and nests are destroyed. Finally, harvested pods are opened in an area distant from the farm.

It is not clear whether this IPM system has been tried on any significant scale or not. The system requires that farmers are trained in scouting and that they are able to distinguish between the different dominant species. A survey by Majer (1974) showed that farmers were indeed knowledgeable about the different ant species as many species had vernacular names. He estimated that one farmer could scout 2 ha of cocoa per day. Recent studies on coconut further indicate the potential of beneficial ants to be used in IPM systems (Way and Khoo, 1992; Löhr, Dar-es-Salaam, pers. comm.).

OTHER CROPS USING IPM COMPONENTS

Other crops illustrate important situations where individual components for IPM interventions are being developed and used.

Banana and plantain

Production in Kenya, Tanzania, Uganda, Burundi and Rwanda is threatened by a weevil (*Cosmopolites sordidus*) and nematodes (*Pratylenchus* spp.). The situation is serious, as these crops constitute the basic food for a large part of the population. A research project funded by GTZ and implemented by ICIPE is making progress with regard to identifying landraces of banana which are resistant or tolerant to weevil and nematodes (ICIPE, 1991b). Cultural measures, especially with regard to hygiene (splitting stems after harvest, removal of dead leaves) play an important role in the control of weevils. The potential of natural enemies as control agents is also being investigated. The International Network for the Improvement of Banana and Plantain (INIBAP) is expected to contribute substantially to the research cooperation and diffusion of results (INIBAP, 1989).

Beans

A CIAT grain legume programme in Rwanda is promoting the cultivation of climbing beans in order to replace low-yielding traditional bush beans, intercropped with bananas (CIAT, 1992). A high-yielding cultivar of climbing bean, locally called *Umubano*, was introduced by CIAT from Mexico. This cultivar produces not only higher yields of beans, but also more tasty leaves which are appreciated as vegetables by farmers. The climbers are generally more tolerant of diseases and more resistant to anthrachnose. Farmers may adapt their traditional cultural control practices to the new cultivar.

Maize

An increasing number of farmers, especially in West Africa, may soon have the opportunity to cultivate varieties of maize resistant to the maize streak virus (IITA, 1986, 1990). These varieties were originally developed by IITA research teams, and are now being used particularly by farmers in Nigeria, where the headquarters of the IITA is located. Similarly, farmers in East Africa may benefit form stemborer-resistant varieties of maize developed by ICIPE research staff in Kenya, and spread through PESTNET. Cultural control methods such as intercropping with cowpea are also components of an IPM system gradually being developed (ICIPE, 1991b).

LIVESTOCK IVM AND TSETSE FLY CONTROL PROGRAMMES

Tsetse flies (*Glossina* spp.) are the principal vectors of trypanosomiasis of livestock known as nagana. This disease is caused by species of the

Trypanosoma protozoan parasites. Nagana may be considered the most important disease of cattle in east, west and southern Africa. Since the beginning of the 20th century, major control efforts have been launched to combat tsetse and its transmitted diseases: livestock populations have been moved from tsetse-infested areas; bush has been cleared to try to create a tsetse-hostile environment; wildlife thought to serve as potential disease reservoirs have been eliminated; frequent applications of chemical insecticides have been used to eliminate tsetse; and livestock have been treated with chemotherapy.

Some of these technologies have had a controlling effect but usually only for a short time, and tsetse has re-invaded the previously cleared areas, demanding new control efforts. The efforts have been costly and sustainable neither for the population nor for most African governments. Over the past 15–20 years it has become clear that other means of control are required if tsetse and trypanosomiasis are to be controlled economically and without risks for the environment. Animal husbandry and crop husbandry in Africa are bound to co-exist without destroying their sustainability.

Resistant breeds

Although chemical control programmes are still being carried out in several countries, many efforts are now directed to developing new control methods through research on trypano-tolerant races of cattle. The existence of an African Trypano-Tolerant Livestock Network illustrates the importance ascribed to this work, which is based on the existence of cattle breeds tolerant to trypanosomiasis, for example, the small N'Dama breed in the Gambia (ILRAD, 1988; ILCA, 1989). Recent studies in the Gambia (Agyemang *et al.*, 1991) show that the N'Dama cattle appear to be more productive with regard to milk than previously thought and therefore should be considered when promoting livestock development in Africa. In areas with a high trypanosome challenge, crosses between trypano-tolerant breeds may be the best option (Frisch and Vercoe, 1986).

The relationship between nutrition and disease is being investigated by units of the African Trypano-Tolerant Livestock Network. Well-fed animals are in a better position to withstand the disease than poorly fed animals (ILRAD, 1988).

Biological control of vectors

Biological control methods against tsetse have been developed since the mid-1970s. Two methods have received much attention: release of sterile tsetse males and trapping. The sterile male release technique is based on the sterilisation of large numbers of pupal males using irradiation. Adult males, which though sterile do have the ability to mate, are released in a number much larger than the fertile males present in a specific locality. They will therefore win the competition with normal males with the result that most eggs are not fertilised.

Trapping of tsetse is used to reduce tsetse populations in several countries (Shereni, 1990). Trapping methods constitute the main technical input in the ICIPE's Tsetse Research Programme, initiated in Kenya in the mid-1970s. The programme has four main components as described by Odhiambo (1990):

- A knowledge-rich strategy, which attempts to develop a comprehensive and holistic understanding of individual tsetse species and their habitats.
- A high-profile community approach in the management of tsetse and trypanosomiasis, since both the tsetse populations and the human communities have a close but separate functional relationship with the animal populations, both wild and domestic.
- The idea of self-sustainability, which attests to the goal of 'meeting the needs of today's population without compromising the ability of future generations to meet theirs', as expressed by the researcher Repetto and co-workers in 1989.
- Placing the ICIPE tsetse supertrap as the basic foundation for a community-oriented integrated pest management programme for tsetse and trypanosomiasis.

The NGU tsetse trap developed at ICIPE is covered with readily available blue cloth. Traps baited with cow urine proved highly effective in an IPM pilot control project at Nguruman in the Rift Valley, Kenya, resulting in strong and reasonably long-lasting suppression of the tsetse population. The Maasai population was highly pleased with not having to treat their animals with pharmaceuticals. This project holds good promise that trapping can form a basis for an IPM strategy for tsetse control on a sustainable basis within the context of community participation (Odhiambo, 1990).

An integrated approach should benefit all partners in the community.

It is therefore essential that any tsetse programme should include an acceptance by the cattle-herding communities to reduce their number of cattle to levels that do not exceed the carrying capacity of the land. This would allow the remaining animals to be well-fed. An efficient control of the vector and its transmitted disease should *not* result in increased numbers of lean cattle, thereby only adding to the ongoing deterioration of African lands, and thus compromising the ability of future generations to meet their needs.

Some scientists have expressed the view that rather than trying to eradicate species of *Glossina* and trypanosomiasis from Africa, which is both expensive and simply not feasible, one should learn to live with the vector by using selective, small-scale integrated vector management (IVM) campaigns in conjunction with trypano-tolerant breeds of livestock and chemoprophylaxis (Hardouin, 1987). It appears that such views are not very far from the control strategies of ILRAD expressed in 1986 (Moloo, 1986).

FUTURE ROLES FOR IPM

Vegetables

Cultivation of vegetables in Africa has become increasingly important because of the rapid growth of towns and cities. Most town people do not have the land to grow their own vegetables, and require regular supplies from the market. During the past 20 years large areas near towns have virtually become vegetable gardens, often under irrigation, to fulfil these needs.

The vegetables grown are the same as those grown in Europe, such as beans, cabbages, carrots, onions and potatos. Some are tropical, such as sweet potato and okra. The pest complex is similar to that of Europe, with the addition of a few more noxious pests.

IPM for vegetable cultivation has still to be developed in sub-Saharan Africa. A regional conference for West Africa arranged by the FAO in Dakar, Senegal, in 1992 was aimed at developing a strategy for the actual groundwork to be laid.

Citrus

While IPM is under development for banana, plantain and mango, there appears to be a gap in the case of citrus IPM in Africa. One example of such activities is the Crop Protection Research Institute in Egypt which, in cooperation with two North American universities, initiated an IPM project on citrus in 1992.

Agroforestry

Trees and shrubs are part of traditional cropping systems all over Africa, and today woody plants continue to supply farmers with a number of valuable products such as fuelwood, timber, fodder, food and medicines. Trees, in particular nitrogen-fixing species, also add to soil fertility, thereby increasing yields of agricultural crops. Increasing population pressure by humans and livestock have reduced tree resources drastically, causing erosion and deterioration of the land and soils over large parts of Africa. Also, mechanisation of agriculture has contributed to the reduction in the number of trees in the cropping systems.

Over the past 20 years, agroforestry has become an important measure to reverse this decline. Agroforestry can be defined as a combination of agriculture or animal husbandry in which woody plants play an important role. The problems of pests in agroforestry systems with introduced trees are scarcely known, and only a few investigations on crop pests in such systems are going on. In some cases it has been noted that farmers are reluctant to adopt tree species in their cropping systems, for instance for fear of weaver birds going to nest in the trees or of insect pests using the trees as alternative or intermediate hosts. The fear of weaver birds is very relevant, and is being addressed in the selection of tree species such as *Grevillia* with slender crowns not very suitable for nest making. Farmers' fear of increased insect pest risk with intercropping with trees may or may not be relevant. In most cases only a time-consuming scientific investigation can give the answer. ICRAF, based in Nairobi, Kenya, should take a leading role in such investigations.

An example from the Gambia shows how farmers can be mistaken in their assumptions. As noted in the case study on pearl millet, blister beetles (*Psalydolytta fusca*) are a very severe pest, sucking grains during the milky stage in August. Farmers reported that this beetle was found feeding on leaves of a local tree species (*Entada africana*) in June–July, and therefore wanted to cut down such trees. A countrywide survey showed that indeed blister beetles were found feeding on this tree but that they belonged to a smaller and less harmful species (*Epicauta* *villosa*), which was believed by farmers to be 'young' *P. fusca* beetles. The farmers' assumptions were logical, as they would have had no means of recognising the blister beetle larvae, which the researchers later proved to live in the soil.

Trees may support a population of predatory ants (*Oecophylla* sp.) which control bugs of *Pseudotheraptus* spp., a serious pest of coconut in East Africa and Côte d'Ivoire. Encouragement and interplanting of tree species favoured by the ants strengthens their ability to compete with other ant species which are not beneficial (Way and Khoo, 1992).

Control of trees as weeds

Examples exist of introduced trees that have become weeds in themselves when planted in a new environment. The most prominent example is *Lantana camara* in Kenya and other parts of East Africa. No efficient, introduced biological agent has so far been found against *Lantana*, though an introduced bug (*Teleonemia scrupulosa*) from Hawaii led to at least some control in Uganda in the 1950s (Waage and Greathead, 1988). Today *Lantana* has in many places become accepted as a useful, though cumbersome hedge plant.

Prosopis juliflora, when introduced into rainfed or irrigated agricultural areas, may also become a pest as has happened in certain localities of Niger. On the other hand, this tree species is extremely useful in very arid areas, for instance when used as the major sand-dune-fixing plant in Mauritania (DANIDA, 1991). The important exotic fodder tree *Leucaena leucocephala* and some other exotic nitrogen-fixing tree species (*Albizia, Sesbania*) commonly used in agroforestry systems all over the continent, may also turn into weeds.

There may develop conflicts of interest when introduced tree species with great potential benefits (soil improvement, fodder, wood) may turn into weeds in good agricultural areas if not managed properly. In the case of *Leucaena*, for instance, it should be cut down once or twice a year before setting seeds. One has to evaluate the pros and cons of a situation before entering into an irreversible classical biological control programme against the introduced tree species which could destroy possibilities for farmers in areas where the tree is a useful component of agricultural development. A new pest, the *Leucaena* psyllid *Heteropsylla cubana*, from Central America, has caused defoliation and death of *Leucaena* plantings in several Asian and Pacific countries (Waage and Greathead, 1988) and has recently been introduced into parts of

Africa. The pest has recently been reported in Mauritius and the Kenya coast and could be disastrous if widely dispersed by winds. ICRAF is conducting a search for new, resistant *Leucaena* varieties (ICRAF, 1994).

IPM FOR STORED PRODUCTS

The larger grain borer, *Prostephanus truncatus*, was first reported in Africa (Tanzania) in 1980, and later from other countries of East and West Africa. The borer is an indigenous beetle species from Central America. While the beetle has become one of the most noxious storage pests, attacking cob maize and dried cassava in Africa, it does little harm in its original surroundings. Among the many natural enemies investigated, the predatory histerid beetle *Teretriosoma nigrescens*, probably specific to the larger grain borer in Costa Rica, is the most promising biological control agent (Boeye *et al.*, 1988; NRI, 1992). This species was released in 1992 in two divisions in Tanzania, where its influence on the populations of larger grain borer will be monitored regularly.

If *Teretriosoma* or other natural enemies prove to be effective when released, it is hoped that IPM can be developed in the near future, thus reducing the enormous losses in both effort and resources now spent to curtail the worst losses in stored products.

Such IPM might also include the development of biopesticides based on bacteria, protozoa and fungi, and the use of crop varieties which are resistant to storage insects. There are great hopes that a united effort by all parties involved with the control of the larger grain borer can lead to success, as expressed at an IITA/FAO Coordination Meeting at Cotonou, Benin (Markham and Herren, 1990).

PROSPECTS FOR IPM IN AFRICA

Major lessons learned

Experiences of the past 20 years show significant progress in developing components for integrated pest management in Africa. Research at international agricultural research centres (IARCs) in particular and at other institutions has yielded highly valuable results in the form of pest-resistant varieties and agents for classical biological control, and reduction of insecticide use without loss in yields. But progress in improving cultural control methods and development of new, more specific pesticides has been much slower. Some crop varieties and a number of biological agents have been dispersed with great success, with substantial benefits for farmers. Other promising varieties and agents are still under development.

A number of regional networks have been set up, some crop-specific and others pest-specific, whose main purpose is to coordinate, assist and improve work in the national agricultural research and extension systems (NARES). However, many NARES suffer from various financial, educational, organisational and administrative constraints, which hamper local research activities.

Extension services all over the continent are sparsely manned (and even more sparsely wo-manned); staff are poorly trained in IPM, poorly equipped, and have insufficient funds to serve more than a few farmers. Most farmers are therefore left without advice on IPM, apart from projects executed by donors or IARCs. This is seriously hampering improvements in yields and agriculture as a whole.

There are, in the view of this author, two urgent problems to address:

1. How to activate NARES to enable them to continue, expand and disseminate the results of IPM activities at IARCs.
2. How to extend IPM messages to farmers under the present limitations.

The considerations below are based on the author's own experience and on the opinions of participants in IPM conferences, in particular the conference on 'Pest Management and the African Farmer' held in Nairobi and sponsored by ICIPE and the World Bank (Zethner, 1989).

Farming communities

It is essential that farmers are directly involved in IPM activities, and that they participate actively at every stage, from planning to evaluation. Without the active involvement by responsible farmers, IPM will never become sustainable. Farmers' priorities, experiences, socio-economic conditions and constraints have to be respected when considering IPM methods.

It is important that any IPM project must benefit farmers in some visible or obvious way. This can either be in the form of increased productivity or by way of savings. At least one IPM component must provide enough benefit to convince farmers to carry out all the other recommended IPM activities without other incentives. One major problem so far has been that few IPM techniques have had enough penetration.

Adequate resistant or tolerant varieties and classical biological control are two categories of IPM components that benefit the majority of smallholders as well as the larger landowners at little cost to them in terms of money or time. Experience shows that farmers are eager to use a resistant variety if this equals or surpasses a normally used variety with regard to yield, grain colour, cooking properties, taste, etc., and if the new variety does not pose serious additional difficulties during cultivation, harvest, transportation or storage. The opinion of farm women must also be taken into consideration (IITA, 1990; Zethner *et al.*, 1990; ICIPE, 1991b).

Some major constraints to introducing IPM in industrial and other cash crops are found at the organisational level. Farmers or tenants may not be willing to commit themselves to the additional labour required in cultural control, scouting, etc., instead of chemical control, if they have been used to a pesticide-based system producing high yields with relatively little labour input. Or, farmers may not want to use the extra effort to increase yields if they can earn cash more easily through other activities (Kiss, 1991b; Zahner, 1991). In such cases an effort must be made to convince the farmer and his/her spouse of the benefits of IPM, including those of cash savings.

Numerous agricultural development projects have counted on the participation of particular interested farmers ('innovators', 'progressive farmers') to introduce new activities. The idea is that the improved techniques will later on be adopted by the majority of farmers. This approach has benefited participating farmers, but the spreading effect has frequently failed to materialise. The procedure for selecting participating farmers requires much sociological knowledge of the local community in order to select persons who are respected by the majority of the community. Village headmen or chiefs may not necessarily be the most respected persons any longer, because of the rapidly changing political situation in Africa. Other relationships based on cooperatives, credit societies, religious organisations, or families, may be more valid. It seems to be particularly important to select persons from different social strata, with whom a large number of farmers (men and women) can associate themselves.

Extension services

Although extension services are considered essential for the introduction of new techniques such as IPM in African agriculture, they are in most cases ineffective. There are several reasons for this. First of all, extension staff are frequently very few in number and are unable to serve even a small proportion of farmers; their salaries and transport facilities are often poor. Second, and even more important, extension staff have usually not received any specific IPM training and, if they perform well, they seldom get any reward or incentive. Last, but not least important, there is a lack of appropriate technologies that take the resource base of the farmer into consideration.

IPM activities in Africa cannot be expected to be taught or implemented by extension service staff alone. Staff must not only train motivated farmers to carry out IPM on their own but also to teach fellow farmers how to implement IPM activities. Therefore, it is essential to include training of extension staff and farmers in all IPM programmes, as well as in more general agricultural projects, and to pay for the necessary additional staff.

Education of staff members to become IPM subject matter specialists seems most sensible. Such people should not only receive training in technical/biological subjects, but also learn how to communicate with farmers. Any IPM training programme must include education in the proper use of pesticides.

Female extension agents are at present far fewer than men, in spite of the fact that rural women in Africa generally put much more work into agriculture than men do. Employment of many more women in extension would help in solving the above-noted problem of communication.

Research establishments

Agricultural researchers employed at NARES are generally expected to work on problems that are of great importance to the farmers. Feedback from farmers and extension staff to guide researchers and ministerial administrators in the identification of research priorities is normally insufficient. Such feedback should ideally be a result of a team (farmers, extension workers and researchers) collaborating in an atmosphere of mutual confidence and respect.

Quite often, however, researchers are not receiving the feedback necessary to guide their choice of research priority. This may be because the researchers do not have the means of reaching farmers, or because they may prefer to carry out their research on research stations, rather than on farms.

Among IPM specialists, it is generally accepted that IPM research as much as it is technically possible should be carried out on farms together with the farmer. This approach may ensure that the most important problems are tackled and eventually solved.

Research themes

The following are among the IPM priority areas requiring further research:

- Methodologies for determining economic thresholds.
- Testing of pesticides, including toxicology.
- Development and testing of biocontrol agents.
- Developing and breeding local crop varieties which are resistant to pests.
- Improvement of cultivation practices such as timely weeding and harvesting.
- Socio-economic and sociological studies.

Such studies are presently part of all programmes of the IARCs whose work is funded by international donors. Their work has already yielded results which have benefited millions of African farmers, such as that on streak-resistant maize varieties. This has partly taken place through regional coordination programmes and networks like the Africa-Wide Biological Control Programme. There is a need for regional coordination of pest control activities for all crops, which should embrace all relevant NARES in the region.

The IARCs have proven that research on IPM components has been a good investment. This justifies a continued and even increased funding to the IARCs and their coordination programmes to involve NARES. Due to the financial difficulties in most African countries, donor support is likely to be required for a long time in the future.

The present challenge is how to motivate researchers at the NARES to continue and expand the research done at the IARCs. The presence of field or sub-stations of IARCs may have a positive influence in countries, like Kenya, where NARES have benefited from IIBC, ICIPE and other international institutions. Another option being increasingly tried is to fund relevant national research programmes.

Governments and donors

Governments and donors should put much more emphasis on IPM components in agricultural projects than they have heretofore been doing. This also includes training of extension service staff and farmers in IPM. The use of IPM in many situations should now be recognised as being not only the best ecological approach but also a competitive economic approach, considering the increasing threat from continued pesticide use and the number of effective IPM components already developed.

Since 1967, the FAO/UNEP Panel of Experts on Integrated Pest Control (FAO, 1967b), which was exclusively an FAO Panel until the early 1980s, has succeeded in promoting IPM among scientists as the appropriate crop protection approach of choice in developing countries. However, only one African government (Sudan) has so far adopted IPM as the country's official crop protection policy. It seems appropriate to revitalise the Panel with the specific task of convincing the 50-odd remaining African governments to officially adopt the IPM approach. Donors' support in this undertaking would undoubtedly contribute much to this end.

In the case of industrial crops and other cash crops, often grown for export purposes, donors and governments must work at convincing pesticide suppliers to change their approach in line with IPM.

At the national level, governments should facilitate the IPM approach through proper pesticide legislation and pricing without subsidies. This would restrict the use of insecticides to emergency situations, and give IPM a chance to become an accepted part of the local crop protection service.

In the planning and implementation of agricultural projects, governments and donors should put more emphasis on IPM components than they have done until now. In crops primarily grown for subsistence with little or no use of pesticides, projects should not be labelled as 'IPM projects', but rather projects in which IPM is seen as a strategy to improve agriculture and farmers' income as a whole. The reason is that it is difficult if not impossible to quantify the benefits from IPM, and thus convince farmers, governments and donors of the benefits.

In industrial and other cash crops, the label 'IPM project' should be retained. Farmers have more resources to invest in IPM for these crops, and benefits can be more easily measured than in subsistence crops. It is gradually being recognised that pesticides in many cases are being overused, and that the increasing cost of chemical control does not pay off, at least not in the medium- and long-term. On the contrary, it is usually observable that pest problems tend to increase with the number of pesticide sprayings.

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APPENDIX: IPM AND IPM-RELATED PROJECTS IN AFRICA (see also Table 1.1)

1. CILSS Départment de Formation en Protection des Végetáux
2. Research and Development of Integrated Pest Management for Basic Food Crops in Sahelian Countries
3. Pest Management Technical Coordination Unit
4. Integrated Pest Management of Crop Borers for Resource-Poor Farmers in Africa
5. Reduction of Food Losses through Insect Pest Management and Use of Small-Scale and Low-Cost Farm Equipment in Africa
6. Pest Management Systems for Subsistence Agriculture
7. Integrated Pest Management for Rainfed Millet in Northwest Mali
8. Rehabilitating the Vallee du Kou Rice Scheme
9. Projet de Recherche sur l'Elaboration d'un Programme de Lutte Intégrée contre les Rongeurs du Riz
10. Maize Breeding Programmes (especially against maize streak)
11. Maize Resistance to Armyworm
12. Millet Breeding Programmes (especially against stem- and spikeborers)
13. Sorghum Breeding Programmes (especially against stemborers and *Striga*)

14. Sorghum/Millet Collaborative Research
15. Strengthening African Agricultural Research Programs: Plant Resistance to Insect Attack
16. Armyworm Programme
17. Lutte Raissonnée contre les Complexes *Striga*/Mauvaises Herbes
18. Improvement of Weed Management in the Production of Basic Food Crops on Small-holdings in The Gambia
19. Strengthening of Plant Protection Activities for *Striga* Control
20. Control of Parasitic Weeds in Africa
21. Resistance in Maize to the Parasitic Weed *Striga* and the Relationship between Infestation and Farming Practices
22. Prevention of Bird Damage in Cereal Production and Improvement of the Plant Protection Service
23. Biological Control of Pests in Major Staple Crops
24. Biological Control of Food Crop Pests
25. IPM for Grain Legumes
26. Biological Control of Bruchidae, Insect Pests of Cowpea in West Africa
27. The Africa-Wide Project for Biological Control of Cassava Pests
28. IITA Cassava Breeding Programmes for Africa
29. Controle Cochenille du Manioc
30. Biological Control of Manioc Pests in Africa: Support to IITA/ABCP
31. Strengthening African Agricultural Research Programmes: Root Crop Research
32. Biological Control of Pests of Sweet Potato
33. Biological Control of the Larger Grain Borer
34. Control of the Larger Grain Borer
35. Integrated Pest and Post-Harvest Protective Project
36. Larger Grain Borer Control and Containment Programme: Larger Grain Borer Control Training Project
37. Integrated Plant Protection
38. Promotion of Biological Control of *Rastrococcus*
39. Lutte Biologique contre la Cochenille du Manguier
40. Lutte Biologique contre la Cochenille de Arbres Fruitiers et des Plants Ornamentales
41. Studies on Banana Weevils and Nematodes
42. IPM of Citrus
43. Biological Control of Coconut Pests
44. Pest and Disease Control in Coffee in Kenya
45. Proposal for IPM in Cocoa in Ghana
46. Development and Application of Integrated Pest Control in Cotton and Rotational Food Crops
47. Pesticide Management in Cotton in Zimbabwe
48. Cotton Pesticide Management in Togo
49. Viruses for Cotton Pest Control in Egypt
50. Development of an Integrated Crop Protection Service
51. Extension Programme for Integrated Pest Management

2 Practice of IPM in South and Southeast Asia

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South and Southeast Asia is the world's most densely populated region, with rapidly growing populations and exploding economic expectations. These factors have put an enormous burden on agriculture in the region. The intensification of crop production programmes with an emphasis on increasingly higher yields has resulted in more intensive fertiliser and pesticide inputs and unsustainable land and water use. Under such circumstances, hitherto minor pests have acquired the status of major pests and pest outbreaks have become more frequent. Furthermore, the symptoms of irrational pesticide use—pest resurgence and development of resistance—are increasing. Excessive pesticide use is also responsible for unacceptable levels of pesticide residues in market produce, health risks and contamination of aquatic and terrestrial ecosystems.

A major characteristic of the region is its large number of small-scale and subsistence farmers. Even though there have been tremendous advances in agriculture in the region in the past three decades, the breadth of change has been disappointing and a large number of these resource-poor farmers still remain unaffected by new technologies.

Integrated pest management (IPM) is now accepted as an ecologically sound and economically viable alternative to chemical pest control. It is also seen as being the most appropriate and acceptable pest control strategy for the great majority of small farmers in the tropics.

There is no doubt that IPM has become a popular idea in Asia, but is it only a new label for the familiar practice of using chemicals? *Many believe IPM to be a myth.* How far has IPM percolated down to the farmers? Obviously, some of the issues which were raised by Rachel Carson over three decades ago in her book, *Silent Spring*

Integrated Pest Management in the Tropics: Current Status and Future Prospects
Edited by Annalee N. Mengech, Kailash N. Saxena and Hiremagalur N. B. Gopalan

(1962), are still very relevant today. There have been some attempts to curb the use of chemicals, but have they been enough? Does the policy environment favour the implementation of IPM?

In recent years, the problems of pest control and concern about the continued use of pesticides in Asia has been the subject of intense debate and discussion. There have been a number of workshops and meetings on IPM in the region. In 1991 alone, there were three international meetings, one in Japan and two in Malaysia. This paper examines the development and practice of IPM in South and Southeast Asia. The extent of pesticide use in the region is reviewed. Changes in policy, legislation and institutional arrangements that can foster the rapid and widespread adoption of IPM in Asia are discussed.

CURRENT TRENDS, POLICIES AND STRATEGIES

Crop protection in Asia is still dominated by an increasing dependence on chemical pesticides. Pesticides were big business in 1962 and are even bigger business today. Twenty years of 'green revolution high-input packages', including the use of high-yielding varieties (HYV) and unecological approaches have made most agricultural institutions and farmers dependent on pesticides. The practice of calendar spraying is still common and crops are treated regularly in anticipation of possible pest attacks. Aerial spraying is still prevalent in many countries of Asia in spite of the well-documented ecological consequences of such practices. Pesticide subsidies of various types remain a major aspect of plant protection policies in many Asian countries. Apart from agriculture, the use of pesticides for other purposes, such as public health and home use, is also increasing.

Adoption of IPM in Asia

The consequences of the injudicious use of pesticides in Asia are well documented and are discussed later in this paper. IPM is now accepted as the only rational approach to correcting this trend and preventing future environmental catastrophes. Almost all the countries of the region have now declared IPM as part of their agricultural developmental policy. The process of converting the concept of IPM into an operational approach has also been started and many IPM programmes are in advanced stages of development and implementation. FAO has prepared guidelines for IPM in rice, cotton, maize, sorghum and vegetables, and has also assisted many countries in their adoption (FAO, 1990; Saha, 1990, 1991).

At the national level, most countries in Asia have plant protection services, usually under their ministries of agriculture and extension services. Pest survey and surveillance programmes have also been established in most countries, notably China, India, Indonesia, Malaysia, Korea, Pakistan, the Philippines and Thailand (Heong, 1988, 1990; Pfuhl, 1988; Sri-Arunotoi, 1988; Saha, 1991). In India, surveillance information is gathered through 32 central stations located in different parts of the country for pest monitoring, forewarning, and timely need-based pest control measures. Recently, these stations have been merged with the newly created IPM units throughout the country. Similarly, there are 156 well-equipped forecasting units established in the Republic of Korea for surveillance of major rice pests. Surveillance systems for rice pests are also operational in Indonesia, the Philippines, Malaysia and Thailand. China has developed strong surveillance programmes for crops like cotton, rice and vegetables. The concept of 'plant health clinics' has also been advocated in India and other countries.

A number of successful IPM programmes have been developed in different parts of Asia in the past two decades. However, although IPM has also been demonstrated to be economically viable, its large-scale adoption by farmers remains limited. For IPM to be adopted on a large scale, it is important to analyse the policy environment under which diffusion of IPM is expected to take place. Is the prevailing framework of agricultural policy in favour of IPM, or does it hinder its implementation?

The policy environment affecting IPM

The prime objective of agricultural policies in Asian countries as they relate to plant protection is to increase agricultural productivity by minimising crop losses due to pest attack. Many official government recommendations are still concerned exclusively with pesticide treatments and not IPM methods. Technology packages in which farmers are encouraged to buy fixed chemical inputs as part of a credit package and apply them according to a uniform time schedule are promoted. Rates of pesticide consumption are often mistaken for progress and the agrochemical industry seems to enforce the impression that it is government policy to encourage maximum use of pesticides.

An important aspect of the policy environment affecting IPM is the question of subsidies. Subsidies for pesticides are considered to be antagonistic to IPM. Subsidies foster an artificially economic use of pesticides and tend to encourage farmers to use them excessively. On the other hand, removal of subsidies, as has been shown in the case of Indonesia, can increase the comparative advantage of IPM and lead to greater adoption. Many governments seem to apply a kind of dual policy: make sure that the farmers apply levels of chemical inputs which they believe are likely to assure desired levels of production, while at the same time pretend to 'promote' IPM by touting judicious and need-based use of pesticides! Similarly, prophylactic applications of pesticides are encouraged by crop insurance programmes which compensate for pest damage only if fields have been treated with pesticides.

Waibel (1990) studied and analysed the pre-conditions for possible 'take-off' of IPM technology in rice using Thailand as an example. Results show that up to now the policy and information environment in Thailand has been in favour of a continued increase in pesticide use. This is more or less true of most countries in the Asian region. IPM programmes must therefore attempt to reverse this situation. Policy-makers must be convinced of the viability of IPM. Wardhani (1991) has listed four policy requirements for the successful implementation of IPM. These are:

- political will to develop, issue and maintain strong policy support,
- solid field research,
- emphasis on human resource development, and
- sufficient resources to sustain implementation and further development of IPM programmes.

Implementing IPM

Traditional pesticide recommendations are readily adopted by farmers because they allow the farmer to decide when and where to use them. Decision criteria appear to be clear, the method is clear and they also appear to be effective, at least in the short run. The use of pesticides, therefore, appears to be a straightforward technology. In contrast, IPM appears complicated, requiring a degree of knowledge and sophistication much above that required for pesticide application.

Traditionally, IPM packages have focused on economic thresholds as the key to decision-making for applying pest control measures, mainly pesticides. There is no real evidence so far that farmers in Asia have adopted the recommended economic threshold levels. In fact, it is difficult to make farmers follow the recommended economic thresholds. According to Waibel and Meenakanit (1988), pesticides are applied on average at pest levels which are only 30% of the present recommended threshold level.

In some pest management programmes, trained agricultural technicians have been employed to monitor fields and apply economic thresholds to tell farmers when to use pesticides. However, in the present approach to IPM, this is not considered desirable and farmers must be taught to monitor their own crops. This approach has been quite successful in the Indonesian National IPM Development and Training Programme, discussed later in this paper. 'Simplistic' approaches such as economic thresholds are being replaced with farmer implementation of ecosystem analysis which fits better with the multifactorial world of farmers (Gallagher, 1992). The farmers' perception of IPM is most important and emphasis has to be made on developing their resourcefulness and management abilities, in effect making farmers 'IPM experts' (Anon., 1991a).

The responsibility for IPM implementation does not rest with governments alone, but also with researchers, industry, traders, farmers, environmentalists, health groups and even consumers. In the Asian scenario, government bodies would have to continue to play a pivotal role in the development and implementation of IPM programmes by not only providing financial support, but also by providing the right kinds of incentives. Vested interests should not be allowed to roll back the progress of IPM.

PESTICIDE USAGE IN ASIA

Are the golden days of pesticide use numbered? A UNIDO report considers pesticide-free agriculture to be unrealistic (UNIDO, 1988). The three decades following *Silent Spring* have seen an unprecedented growth in the pesticide industry. In Asia, the statistics available on pesticide use tend to be quite variable; nevertheless, it is quite apparent that the growth has been faster than in other countries. According to the Asian Development Bank (ADB, 1987), during the period 1980–85, the average market growth rate in the Asia and Pacific region was 5% to 7%. Markets in Indonesia and Pakistan during this period registered

Table 2.1. The pesticide market in Asia in relation to the world market, 1990

Region	Market (US$ billion)	% share
North America	5.4	21.9
Western Europe	6.6	26.7
Eastern Europe	1.9	7.7
South/Southeast Asia*	6.6	26.7
Africa and West Asia	1.4	5.7
Latin America	2.8	11.3
Total world market	24.7	100.0

*Comprised of insecticides (45.8%), fungicides (21.9%), herbicides (29.2%) and other pesticides (3.1%).
Source: GIFAP Asia Working Group (GIFAP, 1992).

a growth rate as high as 20–30% per annum. By way of contrast, the world market was estimated to grow at a rate of some 4.5% each year (Johnson, 1991). These trends have continued in most Asian countries since 1985 except in Indonesia, where pesticide use has actually decreased (Anon., 1991a,b).

The Asian share of the world pesticide market was estimated as 26.7% in 1990 (Table 2.1). Of this, insecticides make up 45.8%, fungicides 21.9%, herbicides 29.2% and others 3.1% (GIFAP, 1992). Half of the total pesticides used in Asia, including the larger share of fungicides and herbicides, are consumed in Japan (Woodburn, 1990; Anon., 1992). South and Southeast Asia is predominantly an insecticide market with the major share going to rice, cotton and vegetables.

The supply and consumption patterns of seven RENPAP (Regional Network on Pesticides in Asia and Pacific) countries indicates insecticide usage to be about 75%, herbicides 13% and fungicides 7% (Figure 2.1). Insecticide share in Bangladesh, Burma, Pakistan and Nepal is over 90%. However, Malaysia is an exception to this rule, as herbicides account for about 75% of the pesticide used, insecticides about 13%, and fungicides and rodenticides 3% and 9%, respectively. This is mainly due to high herbicide usage in plantations of rubber, oil palm and cocoa (ADB, 1987; Anon., 1991b).

All kinds of pesticides continue to be available in the Asian markets. Even today, DDT which has been identified as perhaps the most environmentally damaging of all agrochemicals, continues to be easily

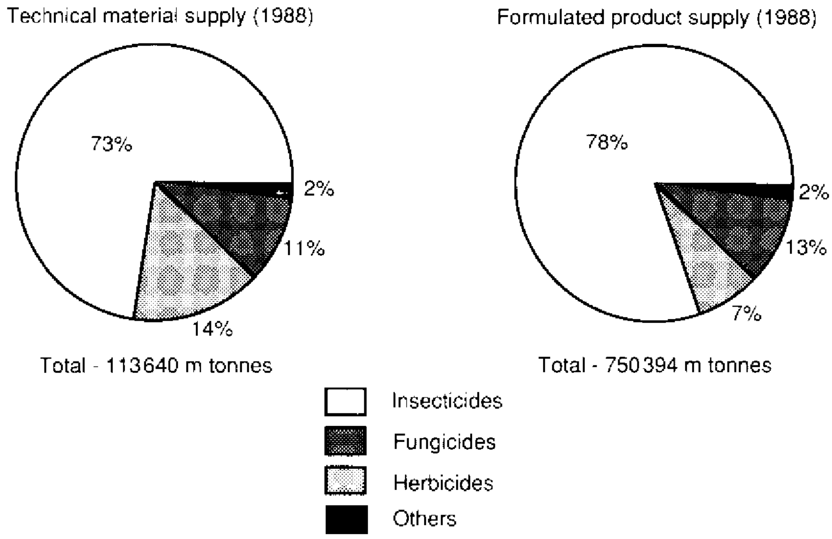

Figure 2.1. Production and import of pesticides in seven countries of Asia: India, Indonesia, Pakistan, Philippines, Sri Lanka, Republic of Korea and Thailand (units are in metric tonnes or kilolitres)
Source: Anon., 1991b.

available in South Asia (India, Pakistan, Sri Lanka, Bangladesh and Nepal). It has been observed that when farmers grow crops for themselves, pesticides like BHC and methyl parathion are more commonly used, as they are relatively cheap. But when farmers shift to commercial crops, they are generally provided with newer pesticides. In addition to the problem of continued use of very toxic compounds, farmers' exposure to chemicals is further increased by poor storage, use of faulty and leaking spraying machines, and lack of protective clothing.

Cropwise consumption patterns

The total cropwise consumption pattern of pesticides is shown in Figure 2.2. Rice consumes over 40% and fruits and vegetables about 33%. The share of plantation crops is about 10% and cotton 8.5% (GIFAP, 1992). These figures, of course, vary from region to region. For instance, in India and Pakistan, the proportion of pesticides consumed on cotton alone is of the order of 50% and 70%, respectively.

The global value of pesticides used for rice was estimated at

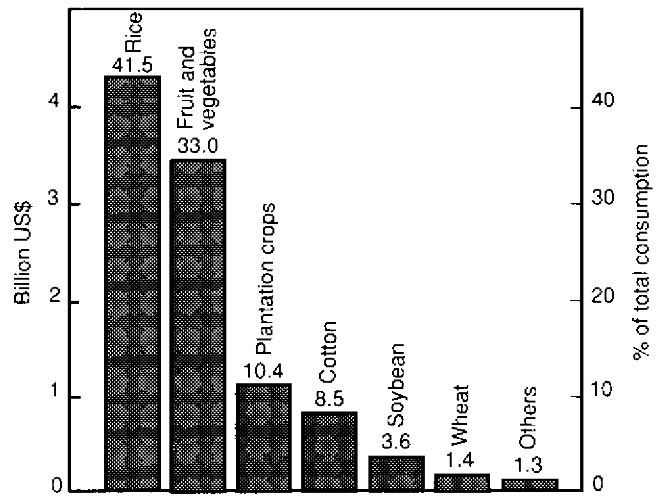

Figure 2.2. The Asian crop protection market in 1990 by crops, showing the distribution and value in billions of dollars
Source: GIFAP, 1992.

US$ 2400 million (2.4 billion) in 1988 (Woodburn, 1990). Of this, the Asian share was 90%. However, 60% of the total pesticides used for rice in Asia are consumed by Japan alone, even though it produces only 3% of the world's rice. Japanese rice growers apply nearly half of the world's rice insecticides and about two-thirds of rice herbicides and fungicides by value, annually. The average annual expenditure on agrochemicals for rice in Japan was US$ 680 per hectare in 1988, compared to US$ 2 to 3 per hectare in India, Bangladesh, Burma, Vietnam and Pakistan; about $5 in China, Thailand and Indonesia; and $14 per hectare in the Philippines. In South Korea the average annual expenditure on agrochemicals approaches $200 per hectare (Woodburn, 1990).

Countrywide consumption and production

China

India and China are the biggest producers and consumers of pesticides in Asia. In China, locally produced pesticides constitute 90% of the materials used. The annual pesticide consumption is 200 000 metric tonnes (Mt) of which 70% are insecticides. China has over 200 pesticide production and formulation units producing over 400 different formulations with an annual production of 650 000 Mt (Anon., 1991b).

India

The trend in pesticide consumption in India during the period 1954–89 shows that it had risen from 434 Mt (technical grade) in 1954 to 24 305 Mt by 1971, reaching 58 980 Mt by 1977–78 (2% of the total world consumption) and 75 418 Mt in 1989, a 22% increase over the decade. The total demand for pesticides in India by the year 2000 is expected to be around 100 000 Mt for agriculture and 44 000 Mt in public health (David, 1992).

India is the second largest manufacturer of basic pesticides in Asia after Japan (Anon., 1991b; Deshmukh and Sawhney, 1991). Fifty-seven technical grade pesticides are manufactured in the country out of a total of 137 pesticides registered. Insecticides make up the major share of the pesticide market (75%). However, in the last few years, there has been a distinct trend towards increasing herbicide use. Eight 'key' pesticides, indigenously manufactured in India, account for more than 85% of total production of pesticides in the country. Three of these, BHC, DDT and malathion account for 55% of total production of pesticides; endosulphan and methyl parathion are also important (Anon., 1991b). DDT has now been banned for use in agriculture but is still available for public health, and BHC use is now restricted. Theoretically at least, no DDT is now used in agriculture.

It is uncertain as to why India continues to use huge quantities of BHC, DDT and malathion in public health, mainly for malaria control. Their efficacy is doubtful, considering the proven insecticide resistance in mosquitoes, not to mention their other undesirable effects on human health and the environment (Mehrotra, 1989). The principal user agencies, the National Malaria Eradication Programme and the Food Corporation of India, seem unable to counter the political pressure for their continued use, in spite of sound technical grounds to support the replacement of these insecticides.

The average per hectare consumption of pesticides in India has risen from 15.4 g/ha in 1960/61 to 440 g/ha in 1989/90 (Anon., 1991b, 1992). Although this consumption is still low compared to the USA and Western Europe (1.5 to 3.00 kg/ha) and in Japan (10–12 kg/ha), pesticide residues in food, especially vegetables and milk, are the highest in the world.

Korea

The Republic of Korea is another major producer of technical grade material. Nearly two-thirds of the demand for technical grade pesticides is met through indigenous production. Insecticide usage accounts for 39%, fungicides 32% and herbicides 22% of the total pesticide consumption (Anon., 1991b).

Indonesia

In striking contrast to the rest of Asia, pesticide consumption in Indonesia has begun to show a downward trend. Indonesia produced 29 570 Mt of formulated products in 1988 which is 50% less than the 59 560 Mt that were produced in 1986. Indonesia has a total installed capacity to produce 13 330 Mt of technical grade material. About 150 formulations are produced utilising both indigenous and imported technical grade materials. Granules constitute 50% of the total formulations produced in the country (Anon., 1991b).

Other countries

In Pakistan, except for the locally manufactured DDT and BHC, all other technical grade materials are imported. More than 200 formulations are available in the market. Of the pesticides imported in 1988, 91.4% were insecticides. Similarly, in Thailand nearly all the technical grade material except for paraquat is imported. All other countries of South and Southeast Asia are completely dependent on imports to meet their pesticide requirements (Anon., 1991b).

Status of pesticide regulations

There is now a much greater appreciation of the problems associated with the use of pesticides than in the previous decade. An excellent account of the significant concerns regarding the effects of pesticide use on environment, health and safety in different countries of Asia can be found in the pesticide manual prepared by the Asian Development Bank (ADB, 1987).

An interesting study was conducted by FAO in December 1986 through questionnaires on the status of pesticide regulations in different countries (FAO, 1989a; Johnson, 1991). The results of this study show

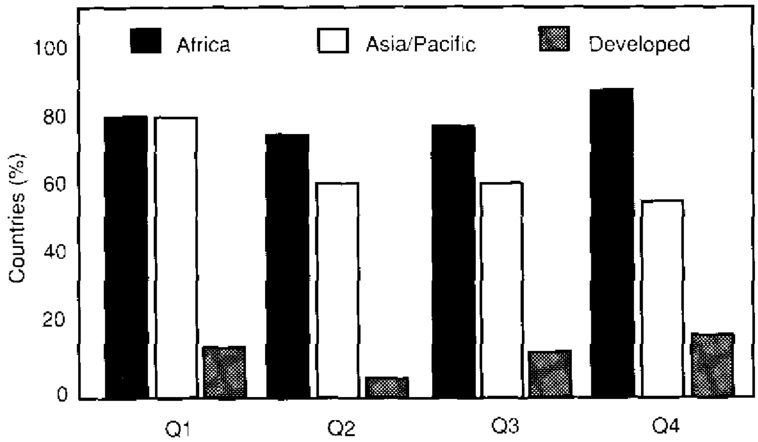

Figure 2.3. Responses to the December 1986 FAO questionnaire of governments in Africa, the Asia–Pacific region, and the developed countries. The questions, related to pest management. (1) Integrated pest management is not promoted. (2) Resistant strategies are not developed. (3) Environmental factors are not studied. (4) Use-import statistics are not collected
Sources: FAO, 1989a; Johnson, 1991.

that despite the emphasis placed on IPM, very little promotion of IPM had been achieved in the Asia/Pacific region (and also in Africa) by 1986. Also, progress on other pesticide-related matters was poor (Figure 2.3). Similarly, the situation on safety and health problems was much worse as compared to the 'developed' world. An interesting aspect here is that a larger number of 'developed' countries had reported the availability of very toxic pesticides and also their presence in food outlets as compared to the developing countries. However, while the 'developed' countries are able to control the availability of pesticides, etc., the countries in Asia (and also in Africa) are unable to control their availability.

Other aspects concerning pesticides such as safe handling and proper use are poorly attended to in Asia and Africa, although most of the countries of Asia have or are in the process of establishing or implementing legislation and regulation procedures. Countries lacking basic laws and regulations are developing them. Countries with more advanced pesticide regulations, such as the Philippines and Malaysia, are expanding programmes into areas of worker protection and monitoring (Gaston, 1986; ADB, 1987; Oka, 1988; Saha, 1991).

Table 2.2. Pesticide legislation in selected Asian countries

Country	Pesticide legislation/registration	Administering authority	Area of control	Methods of control
Bangladesh	Pesticides Ordinance, 1971 (the ordinance was amended in 1980 and 1983)	Pesticide Technical Advisory Committee (PTAC), Ministry of Agriculture	Import and manufacture	Product registration and import licensing
	(Rules promulgated in 1985)			
China	Regulations for Pesticide Registration 1982	Evaluation Committee on Pesticide Registration, Ministry of Agriculture	Import and manufacture	Product registration system
	Regulations for Sale & Use of Pesticides, 1982	Ministry of Agriculture and Public Health Department	Handling and use	Routine inspection
India	Insecticides Act, 1968	Central Insecticides Board, Ministry of Agriculture	Import, manufacture and sales	Product registration, licensing of factories, godowns and shops
	The Insecticides Rules, 1971			
Indonesia	Government Decree No. 7, 1973	Directorate of Food Crop Protection, Ministry of Agriculture	Import, manufacture and sales	Product registration
	Agricultural Ministerial Decree No. 280, 1973		Pesticide registration procedures	
	Decree No. 429, 1973		Labelling and packaging	
	Decree No. 944, 1984		Limitation of pesticides registered	
	Presidential Decree No. 3, 1986			
Malaysia	Pesticides Act, 1974	Pesticides Board, Department of Agriculture	Import, manufacture and sales	Product registration, import permit for research and education

	a) Pesticides Rules, 1976		Registration procedures	
	b) Pesticides Rules, 1981		Importation for research purposes	
Pakistan	Agricultural Pesticides Ordinance, 1971 Agricultural Pesticides Rules, 1983	Agricultural Pesticides Technical Advisory Committee (APTAC), Ministry of Food and Agriculture	Import and manufacture	Product registration and import licensing
Philippines	Presidential Decree No. 1144, 1977	Fertilizer and Pesticide Authority (FPA), Ministry of Agriculture and Food	Import, manufacture and handling	Product registration and licensing to handlers
	FPA Rules and Regulations No. 1, Series of 1977			
Republic of Korea	Agro-Chemicals Management Law of 1957 (revised 1980) Presidential Decree 10195	Rural Development Administration (RDA), Ministry of Agriculture	Import, regulate supply, demand and control on manufacturing plants	Product registration system
	Ministerial Decree 822 and 827, 1981			
Sri Lanka	Control of Pesticides Act 1980 (Implemented 1983)	Pesticide Registration Office, Ministry of Agriculture	Import, manufacture and handling	Product registration system
Thailand	Poisonous Articles Act, 1967 (Amended 1973)	Agricultural Regulatory Divisions, Department of Agriculture	Import and manufacture	Product registration system, licensing after registration; and quality inspection of product in market
	Ministerial Regulation B.E. 2512			
	Ministerial Regulation No. 3			

Sources: Gaston, 1986; ADB, 1987; Oka, 1988; Saha, 1991.

Currently 10 countries in Asia, viz. Bangladesh, China, India, Indonesia, Malaysia, Pakistan, the Philippines, Korea, Sri Lanka and Thailand have pesticide legislations to control production, import, export, handling and use of pesticides (Table 2.2). It appears likely that all the countries in the region will have basic regulatory structures in place within the next few years. Pesticide regulations in all countries have been modelled on the FAO Guidelines for Registration and Control of Pesticides (ADB, 1987; Saha, 1991).

The weak point in existing pesticide regulations in Asia is, perhaps, not so much the content of the regulations, but their enforcement. The following are the main constraints in this respect:

- lack of well-trained personnel to enforce the provisions of the regulations,
- inadequate physical facilities such as residue testing laboratories,
- quality control, and
- lack of public awareness and ignorance of farmers (ADB, 1987).

Pesticide companies play on the apprehension of growers and governments. Trade literature and pronouncements place great emphasis on the good points about pesticides—the extra yields, the convenience, their role in modern efficient farming, etc. Also, people are led to believe that use of pesticides is already under strict control and that the industry's and even the official government view is that pesticides, if used properly, pose no risk to health and the environment.

It appears that pesticide use will continue in the region for quite some time. What is needed now, perhaps, is a genuine change of heart in the approach to pest control so that reducing pesticide usage becomes part of good agricultural practice.

STATUS OF IPM FOR RICE

More than 90% of the world's rice is grown and consumed in Asia and this crop alone accounts for 35 to 60% of the calories consumed by 2.7 billion Asians. Rice in Asia is planted on about 145 million hectares, or about 11% of the world's cultivated land. Rice is a very 'political crop' in Asia. Since most of it is grown for national consumption (only 2.4% is traded in the world market), any disruption to its supply has repercussions on food security in the region. It is estimated that an increase in production of over 20% is required by the year 2000 from a 1987 production level of 460 million tonnes, and an increase of 65% by the year 2020 (IRRI, 1989). According to Norton and Way (1990), the implications of this for pest management are two-fold: first, some of this increased production might be obtained by reducing the losses caused by current levels of pest attack. As much as half of the potential yield of rice may be lost due to pests.

Secondly, the changes in production practices and the more intensive rice cultivation that will be necessary to achieve this increase in production could have an unfavourable effect, both on the status of future pest problems and on farmers' ability to deal with them.

Rice is probably the world's most genetically diverse crop. About 120 000 varieties are grown across an extensive range of climatic, soil and water conditions. Rice losses in Asia due to pests may vary from 20% to 50% of potential production (Cramer, 1987; Litsinger *et al.*, 1987; Norton and Way, 1990). Major insect pests include the brown planthopper (BPH), *Nilaparvata lugens*; the rice hispa beetle, *Diclasdispa armigera*; the rice gall midge, *Orseolia oryzae*; and the stem-borers, particularly *Sesamia*, *Chilo* and *Scirpophaga*. In India, intensive usage of pesticides has had serious ecological consequences, resulting in the emergence of formerly minor pests such as the leaf folder, the white-backed planthopper and the green leafhopper as major pests, and in the development of resistant biotypes of the brown planthopper. Rodents are also important pests in rice agro-ecosystems. Amongst the diseases, rice blast, sheath blight, bacterial blight and virus diseases, particularly tungro virus, are considered important. In addition, a wide variety of weeds including *Echinochloa* are known to constrain rice yields.

The indiscriminate use of pesticides in rice has resulted in a control crisis in several countries of Asia, highlighting the need for alternative insect pest control techniques (Kenmore, 1987). In the Philippines, rice farmers have markedly increased their use of insecticides during the last 30 years. During the early 1950s, insecticide use was very low but by the mid-1980s this increased to over 95% (Kenmore *et al.*, 1987). This example is typical of other regions of Asia (Shepard, 1990).

The resurgence of BPH provides a typical example of a technology-induced pest problem, in this case making a species that was a non-pest in tropical Southeast Asia into the most serious pest of this region (Norton and Way, 1990). The sequential crops of highly fertilised susceptible varieties provided ideal conditions for rapid build-up of the pests and the most severe outbreaks occurred when certain of the insecticides used had a disastrous effect on the natural enemies of BPH.

Pest control programmes for rice are now operational in many countries of Asia. Use of resistant varieties and chemical pesticides have been the major tactics. Some cultural practices are advocated but these generally play a minor role in most rice pest control programmes. Also, the role of biological control agents has been largely overlooked. One bright aspect is that pesticide usage per hectare had declined from 263 g/ha in 1985 to 190 g/ha in 1989–90 (Anon., 1992).

Host plant resistance

Host plant resistance has been very important in rice IPM. As pointed out by Heinrichs (1988),

> in the last few decades remarkable progress has been made in the development of insect-resistant rice varieties and the development of integrated control systems in which these varieties are a key tactic. Rice is without equal in the extent to which insect resistance has been incorporated into high yielding varieties and in the extent to which these varieties are being commercially grown by farmers over millions of hectares in Southeast Asia. However, much remains to be done and the potential for IPM systems for rice is great.

The brown planthopper (BPH) provides a good example of this approach. Genes for resistance to BPH have been incorporated into several improved cultivars. The first BPH-resistant cultivar, IR-26 containing bph-1 gene, was released by the International Rice Research Institute (IRRI) in 1973 and became widely adopted by farmers in the Philippines, Indonesia and Vietnam. However, after three years of large-scale cultivation, it became susceptible because of the development of a new biotype. IR-36 with bph-2 gene replaced IR-26 in 1965–77 and by the early 1980s it was cultivated on over 11 million hectares of riceland in Asia. IR-36 and other cultivars with the bph-2 gene have now remained resistant to BPH for over 15 years. A new biotype capable of damaging cultivars with bph-2 gene did appear in small areas in Indonesia and the Philippines in 1983 but did not become widespread. As a precaution against the spread of this biotype, cultivars with bph-3 genes were subsequently released by IRRI (Khush, 1992). According to Khush (1992), so far three genes for resistance have been utilised as part of IRRI's sequential release strategy. IRRI still has a stockpile of six genes in addition to the new genes being transferred from the wild species.

Biological diversity

The importance of conservation of natural enemies in rice fields is now well recognised. The disruption caused by insecticides throws the system out of balance by killing the rice pest predators as well as the pests. With fewer predators present, herbivore pests such as the brown planthopper can re-establish and increase rapidly (IRRI, 1991). It is said that a typical rice field in the tropics supports 800 species of friendly organisms—spiders, wasps, ants and pathogens, that if recognised and protected, will control 95% of insect pests without pesticides (Anon., 1991c).

In studies on the biodiversity of prey and predator species in irrigated rice fields, it has been found that the diversity of insect fauna increased with crop age up to maximum tillering. Hopper densities were lower when populations of such predators as mirid bugs, spiders and ripple bugs were higher. In fields sprayed with insecticides, biodiversity was significantly lower.

National programmes

According to Shepard (1990) the total insecticide applied today could be reduced by more than 50% without yield loss in most parts of South and Southeast Asia. The case of pesticide usage on rice in Bangladesh is illustrative. Until 1974, 100% subsidy was in practice as the government procured the pesticides and gave these to farmers. It was reduced to 50% in 1974 and completely abolished in 1979. This had a dramatic effect resulting in reduction of the pesticide-treated area from 5.12 million hectares in 1972–73 to only 0.263 million ha in 1986–87, with no appreciable reduction in rice yields. In fact, irrespective of the quantity of pesticide used, rice yields appear to be steadily increasing. The increase in yield may, of course, have been due to many factors, such as newer and better varieties, better fertiliser management, increased areas under irrigation, etc. However, as illustrated in Figure 2.4, a spectacular reduction in pesticide use has had no adverse effect on rice yields in Bangladesh (Ramaswamy, 1991).

IPM efforts in rice have paid rich dividends in the form of bringing about a change in the perception and attitude of extension workers. It

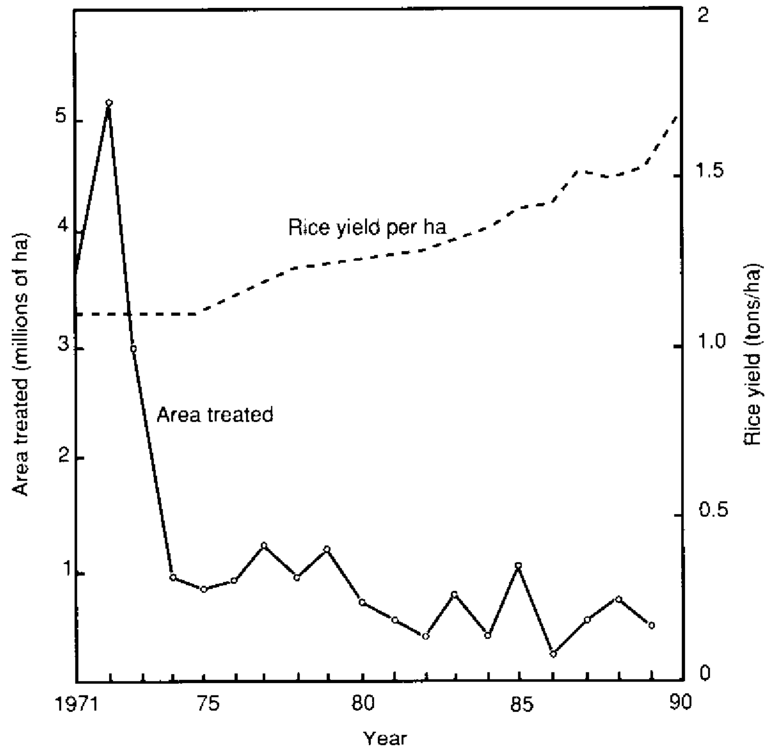

Figure 2.4. Area of rice crop with pesticides and rice yield per hectare in Bangladesh from 1971 to 1990
Source: Ramaswamy, 1991.

has also been clearly demonstrated that the IPM approach can yield greater economic returns, besides other benefits to the ecosystem (Kalode and Krishnaiah, 1991). The main feature of the rice IPM packages in India has been the use of resistant varieties. Other items include modified cultural practices such as raising a community rice nursery, prophylactic treatment through root dipping of seedlings, proper planting, spacing, conservation of biocontrol agents, pest surveillance and monitoring of economic threshold levels of pests, and need-based application of selective pesticides. These technology packages have been translated into action by field demonstrations, and training of state extension functionaries and farmers.

An IPM success story: the Indonesian example

Rice is the most important agricultural commodity in Indonesia, occupying about 60% of the total area devoted to food crops. Traditionally, Indonesia was the world's largest importer of rice. The large-scale adoption of the packaged Green Revolution technology enabled the country to achieve self-sufficiency in 1984 (Oka, 1990; Wardhani, 1991). During the early years of the intensification programme, pest control was only by pesticides applied at regular intervals three or four times during the rice season. Apart from ground sprays, aerial spraying was also resorted to for controlling heavy infestations of stemborer such as in West Java in 1967–68. Pest problems increased enormously in these areas. The brown planthopper (BPH), *Nilaparvata lugens*, which was considered only a minor pest became the most important pest. The estimated loss to the rice crop in the 1976–77 rice season was 350 000 tonnes of milled rice valued at more than US$ 100 million. In addition, the rice tungro virus (RTV) transmitted by the green leafhopper, *Nephotettix virescens*, became a major threat. An outbreak of white stemborer, *Scripophaga innotata*, occurred in West Java affecting 75 000 ha causing a yield loss of over 40%.

When BPH broke out, more than one million fields were totally blanketed with air sprays in Java and Northern Sumatra. Similarly, during the outbreak of RTV in Bali in 1981–82, about 12 000 ha were air-sprayed to control the green leafhopper. Pesticides were considered as an insurance against pest attack. Farmers were given pesticides at heavily subsidised rates and were also given training in the use of pesticide application equipment. The consequences of overuse of pesticides began to become evident in 1984; the population of BPH exploded in 1986, affecting most rice growing areas of Indonesia. Subsidies on insecticides of over US$ 100 million per year were expended without achieving the control of BPH and outbreaks continued despite heavy pesticide use. It was subsequently established beyond doubt that BPH outbreaks had been *caused by, and not in spite of*, massive pesticide applications (Wardhani, 1991).

According to Whalon *et al.* (1990), three factors which contributed to the failure of chemical control in Indonesia were (i) the resurgence of BPH after insecticidal applications, (ii) the elimination of natural enemies, and (iii) the development of resistance in BPH. Furthermore, even though BPH-resistant varieties were available, lack of crop rotation and staggered planting provided a continuous food source for

BPH. This, coupled with high doses of nitrogenous fertilisers and injudicious use of broad-spectrum pesticides, led to dramatic increases in pest populations.

The IPM concept was officially adopted in 1979, and was followed by strengthening of the plant protection services. However, until 1986, pesticides were being used in abundance and subsidies remained massive. A bold initiative by the Indonesian government was taken by issuance of Presidential Decree No. 3 of 1986, banning 57 registered brands of broad-spectrum insecticides for use on rice.

Only a few narrow-spectrum insecticides were allowed to be used against rice pests. This action halted one of Asia's most serious environmental crises. Following the Decree, pesticide subsidies were gradually decreased from 70–75% in 1986 down to around 40–45% in 1987 and in January 1989 the subsidies were completely withdrawn. The Decree has demonstrated the strong will of the Indonesian government and its commitment to maintaining self-sufficiency in rice production, while protecting the environment and human health (Oka, 1990; Wardhani, 1991).

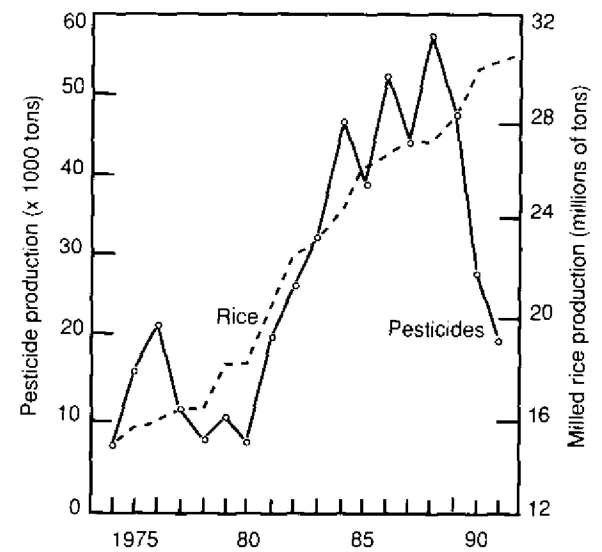

Figure 2.5. Pesticide usage and rice production in Indonesia. Pesticide subsidies were withdrawn completely in January 1989 under the National IPM Programme
Source: Anon., 1991a.

In 1991, five years after the Presidential Decree, and six rice seasons after the subsidy was abolished, rice production had risen 15% from 1986 levels and pesticide use had become decoupled from production packages, falling 60% during the same period (Figure 2.5) (Oka, 1988, 1990; Anon., 1991a; Siswomihardjo, 1991; Wardhani, 1991). Thus, in the world's fifth most populous nation, well-considered macro-economic adjustments have benefited farmers, consumers and the government, and have drastically reduced environmental damage (Wardhani, 1991).

According to Wardhani (1991), the National IPM Programme in Indonesia represents a social movement. It links the scientific development of ecological concepts with intensive field training of farmers in sound field management technologies. It represents one of the first large-scale examples of a 'second generation Green Revolution technology' which is compatible with environmental conservation, public health and farmer profitability.

Regional IPM programmes

Several agencies and institutions are involved in rice IPM development and implementation in Asia. The FAO Intercountry Programme for Integrated Pest Control in Rice in South and Southeast Asia, which was started in 1980, has trained over 400 000 farmers in the practice of IPM, and succeeded in reducing the use of broad-spectrum insecticides in participating countries. Reduction in pesticide subsidies for rice has also received the attention of the governments of these countries (Ramaswamy, 1991; Saha, 1991).

The Integrated Pest Management for Rice Network (IPM-R) was initiated in 1990 with coordination by IRRI. Each participating country has organised a research team of scientists and extension specialists. Interdisciplinary representation involves plant protection sciences, social sciences and development communication (IRRI, 1991). At present, IPM is being practised on about 4.9 million hectares of irrigated rice in Asia out of a total of 133 million ha (Norton and Way, 1990). The successful experiences of IPM programmes on rice gathered during the past 10 years are now being extended to larger areas in a number of countries. Since rice is frequently part of a larger cropping system involving other crops in rotation, an IPM approach across the entire rice-based cropping system is desirable, in order to promote reduction in pesticide usage generally, and thereby to enhance conservation of useful natural enemies which carry over between crops (IRRI, 1991).

IPM IN VEGETABLES

The Asia–Pacific region produces more than 200 million tonnes of vegetables, accounting for about 49% of the world's vegetable production; China and India together account for about three-quarters of the region's vegetable production (Singh, 1990a). Vegetables are important supplementary sources of food and nutrition. They are also one of the major sources of cash for small farmers. A wide variety of vegetables are produced in Asia. These include crucifers, such as cabbage, chinese cabbage, cauliflower and radish; solanaceous vegetables, mainly tomato, egg plant, pepper and potato; cucurbits, mainly cucumber, watermelon and pumpkin; and legumes, mainly peas and beans. In addition, onion, garlic and okra are important.

Excessive use of chemical pesticides has become a matter of great concern all over Asia. According to the *FAO Report of the Expert Consultation on IPM in Vegetable Crops*, the situation of crop protection in vegetables in the region has entered the 'crisis phase' (FAO, 1989b). A wide range of insecticides and fungicides are used on vegetables. Spraying is done frequently, the dosages applied are in many cases higher than the recommended rates and application of mixtures or 'cocktails' of chemicals is common. Also, most farmers apply pesticides on their vegetables close to harvest either because of ignorance or deliberately to maintain the cosmetic quality of their produce (Iman *et al.*, 1986; Rushtapakornchai and Vattanatangum, 1986; Chen and Yeh, 1990; Di, 1990; Guan-Soon, 1990).

The problems arising from overuse of pesticides in vegetables include development of pest resistance to pesticides, environmental contamination, increased health hazards to applicators including pesticide poisoning of farmers, danger to consumers of high toxic residues on market produce, and rising production costs (FAO, 1989b; Di, 1990; Guan-Soon, 1990).

According to the *FAO Report of the Expert Consultation on IPM in Major Vegetables*,

> progressive resistance development to pesticides in major vegetable pests is a very serious problem. It constitutes an important underlying cause of the pesticide dependency in farmers. An insidious danger is that it subtly drives farmers deeper and deeper into a state of desperation to constantly seek for stronger pesticides, while at the same time trapping them with the vicious cycle of pesticide dependency. (FAO, 1989b).

The development of IPM programmes for vegetable pests varies among the countries in Asia (FAO, 1990; Guan-Soon, 1990). IPM of crucifer pests, however, has been developed to an advanced stage in many countries, mainly because of the problems encountered in chemical control of the diamondback moth (DBM), *Plutella xylostella*, which is the most important pest of crucifers throughout the region. Amongst other pests, the melon fly, *Bactrocera cucurbitae*, and *Thrips palmi* are important on cucurbits; *Heliocoverpa* (*Heliothis*) *armigera* affects tomato; bean fly, *Ophiomyia phaseoli*, is one of the most serious pests on beans; *Leucinodes orbonalis* affects egg plant, and *Spodoptera exigua* and *Agrotis* spp. are of economic importance throughout the region.

China

IPM programmes have been successfully initiated in China, the main feature being the production of 'non-polluted vegetables'. Over 200 cities in 22 provinces have been covered under this programme, which includes the use of resistant varieties, cultural manipulation and biological control, including the use of *Bacillus thuringiensis* (*Bt*) and the trichogrammatid egg parasites. The use of pesticides on vegetables has been restricted and pesticide residues are regularly monitored. The policy slogan of plant protection in China has been, 'Taking Prevention First and Carrying on Integrated Pest Control' (Saha, 1990). Survey reports of non-polluted vegetable production in China indicate that about 85% of losses due to pests and diseases can be saved and that these vegetables fetch an increased price of 10% or more (Guan-Soon, 1990; Qiu, 1990; Yi, 1990).

India

In India, vegetable farmers are notorious for excessive use of pesticides. A wide range of broad-spectrum insecticides are still in use including compounds such as BHC, methyl parathion, nicotine sulphate and elemental sulphur. Included amongst the fungicides are several organomercury compounds (Pawar, 1990). Some of the highest concentrations of residues have been found on vegetables sold in urban markets in India. For example, Butani and Jotwani (1984) report as much as 35 ppm of DDT in spinach and 50 ppm of BHC on cauliflower and cabbage. Apart from these two compounds, a number of other pesticides have been detected far above the maximum residue limits in fruits and vegetables (Anon., 1987). Vegetable farmers are also known to add pesticides to their produce after harvest. For example, methyl parathion is sprayed on cauliflower to give it an extra white appearance and okra is dipped in copper sulphate to make it look greener (Anon., 1989a).

IPM technology packages have been developed and a number of vegetable IPM programmes have been successfully initiated in the country. However, the adoption of IPM by commercial vegetable growers remains limited because of the quick and high benefit-to-cost ratio of using chemical means of control (Pawar, 1990).

Malaysia

Vegetable IPM in Malaysia has largely concentrated on the diamondback moth. It combines the use of biological control agents with judicious application of selective insecticides. Pilot trials with farmers have been evaluated to demonstrate their practical feasibility and to guide participating farmers to, 'Think IPM' (Lim, 1988; Guan-Soon, 1990; Saha, 1990).

IPM programmes for vegetable pests have been successfully launched in the Philippines, Indonesia, Thailand and Vietnam. Many other countries, however, such as Bangladesh, Sri Lanka and Pakistan are yet to exploit the non-chemical alternatives for vegetable crops, (FAO, 1989b; Guan-Soon, 1990; Saha, 1990).

The diamondback moth

The diamondback moth (DBM), *Plutella xylostella*, is a common concern among all countries in Asia. DBM has become the single most important factor adversely affecting crucifer production in the Southeast Asian region, approaching a situation similar to the well-known cotton pest control programmes in Central America which wiped out the cotton industry (Lim, 1988; Talekar, 1991). Farmers have been using chemical insecticides to effectively control DBM for two decades. However, in recent years these same insecticides have failed to provide control of DBM and the pest has now developed resistance to practically all groups of chemicals. The farmers have resorted to either using higher dosages or to mixing chemicals. These practices have not only resulted in the resurgence of DBM due to destruction of its natural enemies, but also in the emergence of previously minor pests such as armyworms (*Spodoptera* spp.), cabbage head caterpillar and cabbage webworm as major pests in Southeast Asia (Talekar, 1991). As pointed out by Lim (1988), there is little choice except to pursue an integrated pest management strategy for DBM control which incorporates economic, social and ecological considerations. Should the IPM approach not be practised and the current trend of unilateral use of chemicals be allowed to persist, then a 'disaster phase' may be inevitable.

Biological control

IPM technologies have been developed and demonstrated as feasible alternatives in many countries. Generally speaking, the IPM for DBM includes use of the parasitoids *Diadegma semiclausum*, *Cotesia plutellae*, *Diadromus collaris* and *Trichogrammatoidea bactrae*, application of *Bacillus thuringiensis* (*Bt*) preparations, cultural practices and need-based use of insecticides. The Asian Vegetable Research and Development Centre (AVRDC) initiated an inter-country IPM programme (AVNET) for DBM in 1989 which is funded by the Asian Development Bank. The programme includes mass-rearing and exchange of key parasitoids among participating countries, field establishment of parasitoids, and training of technicians. This programme has been quite successful.

In Malaysia, conservation of the indigenous larval parasitoid, *C. plutellae* and establishment of two exotic parasitoids, *Diadegma semiclausum* and *Diadromus collaris* have formed the basis of IPM in the Cameroon highlands of Malaysia (Loke *et al.*, 1992). In addition, use of *Bt* is recommended if the population reaches the economic threshold. Introduction of *D. semiclausum* and conservation of *C. plutellae* along with limited sprays of *Bt* are parts of an IPM strategy for DBM in the highlands of Taiwan. Efforts are also being made to convince farmers not to spray any chemical insecticides (Talekar *et al.*, 1992). In the Philippines, IPM has been largely successful in the lowlands with inundative releases of *C. plutellae* and *T. bactrae*. Pilot projects to demonstrate the effectiveness of this approach have been recently started (Morallo-Rejesus and Sayaboc, 1992). Successful control of DBM has been demonstrated in the lowlands of Thailand by releases of *T. bactrae* and *T. bactrae* and *C. plutellae* and use of the yellow sticky trap which attracts DBM adults (Rushtapakornchai *et al.*, 1992). In Indonesia, *D. semiclausum* effectively parasitises DBM in the highlands. However, in the mid-level lowlands where crucifers are also grown, it is unable to survive (Sastrosiswojo and Sastrodihardjo, 1986).

Trap crops

IPM techniques based on utilisation of mustard as a trap crop have been developed in Southern India (Srinivasan and Krishnamoorthy, 1991a). Mustard attracts 80–93% of DBM and almost the entire population of leaf webber, *Crocidolomia binotalis*, and stemborer, *Hellula undalis*, which are also major pests of cabbage.

Neem

A spray of 4% neem seed kernel extract (NSKE) at head initiation stage can effectively check DBM. This method has been extended and adopted by a large number of farmers in the state of Karnataka in India (Srinivasan and Krishnamoorthy, 1991b; Srinivasan, 1992). The need for widescale adoption of IPM in vegetables to replace a unilateral chemical approach is well recognised and appreciated in all the countries of Asia. Efforts must be made at all levels to remove the misconception that pesticides are essential for high profits from vegetables. In the case of vegetables, perhaps more than with any other crop, the strategy must focus more on the consumers whose market demands can have immense influence on farmers' acceptance of IPM. Overall, it appears that sufficient information has been generated for the development of IPM programmes for vegetables in many parts of Asia. However, as yet, these programmes have not been widely extended, with few exceptions, to the farmers.

IPM IN COTTON

Cotton is grown in at least 12 countries in Asia. In 1989–90, 44% of the world's cotton was produced in Asia. It is the main cash crop of China, India and Pakistan and it is also important in Thailand and Myanmar. Cotton has been plagued with more pesticide-associated problems than any other crop. Because of potentially high economic returns, cotton farmers tend to use more fertilisers, more intensive irrigation and more pesticides than on any other crop. The cost of insecticides alone may account for nearly 40% of the total cost of cultivation. Despite this input, cotton production in the region is constrained by low yields per hectare and frequent, occasionally disastrous, pest problems (Anon., 1991d).

Cotton is attacked by a variety of pests. Of these, *Heliocoverpa (Heliothis) armigera* and *Bemisia tabaci* have become the most important resurgent pests, mainly due to excessive pesticide applications and the elimination of their natural enemies from the cotton agro-ecosystems. As these two pests also move seasonally between cotton and food crops such as grain legumes and vegetables, pesticide resistance which may develop as a result of pesticide use on cotton also makes the insects harder to control on other crops. The other important pests of cotton in Asia are the pink bollworm, *Pectinophora gossypiella*, the spotted bollworm, *Earias* spp., jassids, thrips, aphids, spiders, mites and several species of bugs. The increasing problems due to continued high usage of pesticides in cotton has made the adoption of IPM an imperative and has given urgency to the need to develop ecologically viable and economically feasible alternative technologies.

India

In India, cotton consumes 50% of the insecticides used annually in the country, even though it occupies only 5% of the total cultivated area. While pesticide usage per hectare has declined in food grains, its usage in cotton has increased from 2.4 kg/ha in 1985 to 2.7 kg/ha in 1989–90 (Anon., 1992). Significantly, 80% of synthetic pyrethroid consumption is confined to cotton alone. Research results have shown that the dependence on insecticides can be considerably reduced by adoption of the IPM approach which includes cultural and mechanical manipulation, biological control by timely release of parasites and predators (mainly *Trichogramma* spp.) and *Chrysoperla* (*Chrysopa*) spp., the nuclear polyhedrosis virus, and the judicious use of insecticides (Verma *et al.*, 1990; Singh, 1991a; Sundramurthy and Chitra, 1992). The benefits of IPM have also been conclusively demonstrated in farmers' fields through operational IPM projects in some of the more progressive cotton-growing states, especially Tamil Nadu and Gujarat. These results show that an IPM system for suppression of insects can maintain the high productivity of cotton varieties and hybrids, increase the abundance of natural enemies and reduce the cost of insecticides as shown in an 'IPM village' (Figure 2.6).

The recent cotton disasters (whitefly in 1983 and 1984; *H. armigera* in 1987 and 1988) in Andhra Pradesh and other cotton-growing states in India and the resultant socio-economic problems have attracted a lot of public attention. For IPM, these disasters have come as a blessing in

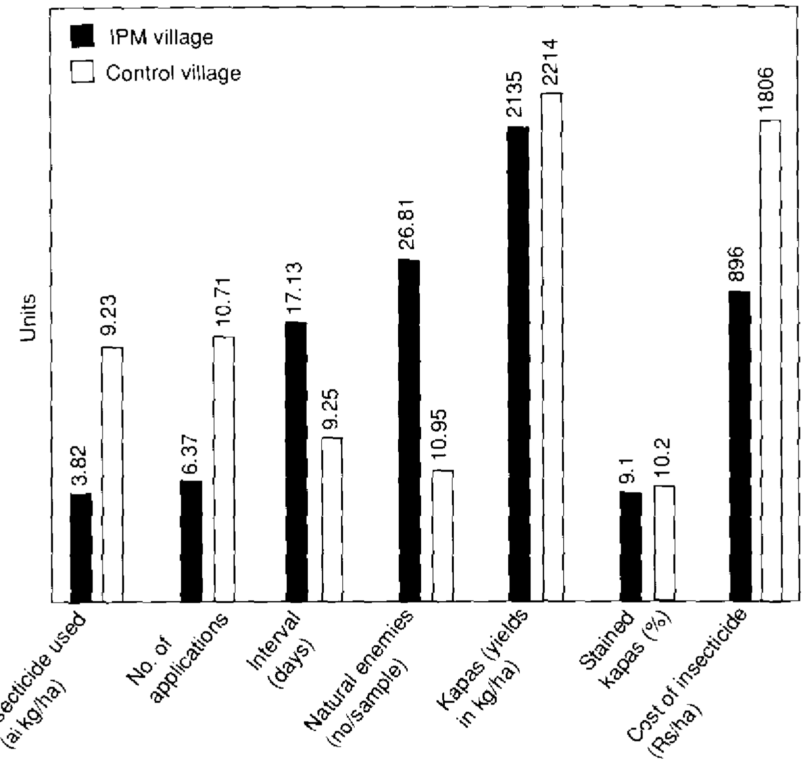

Figure 2.6. Utilisation of insecticides, yield of seed cotton (kapas) and activity of natural enemies in an IPM village (ai = active ingredient)
Source: ICAR, 1989.

disguise. Cotton-growers and extension workers are now much more conscious of the problems associated with the excessive use of insecticides and are more willing to accept the IPM approach. The surveillance activities by both state and federal agencies have been strengthened and the number of sprays have been reduced from as many as 20 to 3–6 applications in most cases. There is greater vigilance against the sale of spurious chemicals. Apart from this, the pesticide industry itself has become concerned about the misuse of chemicals and the increasing incidence of pesticide resistance. These companies have set up their own communication and extension programmes and are working with government agencies in conducting demonstration trials for the benefit of farmers.

China

In China, annual production losses due to pests are estimated to be 25–40% of the potential yield. Several IPM programmes have been initiated in the country since 1985. Successful implementation of these programmes has been possible through the coordinated efforts of administrative, technical and scientific personnel. A good example is the cotton-growing area north of Shihezi in northwest China (Matthews, 1991). Here, the number of insecticide applications has been reduced over a 10-year period from over 10 applications to an average of 1.5 by successful implementation of an IPM programme. The crop is examined for pests every five days and insecticide applications are based on locally devised thresholds, the level of which depends on how many natural enemies are present (Matthews, 1991).

Since the 1980s there has been a rapid expansion of cotton–wheat intercropping in the North China region. Double-cropped area increased from 0.4 million ha in 1978 to 2.3 million ha in 1993, or about 65% of the total cotton land. Compared to the monocrop, the cotton–wheat intercropping system is more diverse and stable, the incidence of major pests less severe, and the presence of natural enemies more abundant. The suppression techniques used for early-season pests include habitat modification through cultural practices, preservation of beneficial species by intercropping wheat with rape, NPV to control the first generation of cotton bollworm (on wheat), and trapping (high-voltage lights and use of a maize trap crop). In 1991–93, an IPM project recommended by the Cotton Research Institute was implemented in Neihuang County of the Henan Province in an area of 1800 ha. Compared to non-IPM areas, damage from the major cotton pests decreased by 20–35% and per unit lint increased by 25–35%. The total net economic return from insect pest control for the three years was US$ 0.9 million, with an input : output ratio of 1.5 : 10.0 (Xia Jingyuan, 1994).

An IPM project planned for Shandong cotton fields has identified 150 natural enemy species. Of these, 25 species in five groups are cited as being particularly important and should be targeted for conservation and utilisation (Xu Lirui and Ma Deling, 1994).

Pakistan

Cotton pest control in Pakistan has been based on the use of chemicals and there are now signs that the situation is deteriorating into the familiar pesticidal spiral. The cotton IPM programme in Pakistan was developed in the late 1970s and is being implemented through Cotton Maximization Programmes. The Directorate of Pest Warning and Quality Control of Pesticides has a network of field workers to assist the cotton farmers in implementation of the IPM programme. A pest scouting system has been developed and many farmers have been trained (Ahmad, 1992).

Thailand

Cotton production has been on the decline in Thailand for some years, mainly due to problems of pest control. Cotton IPM was initiated in Thailand for five years (1984–88) as part of a project on IPM for secondary crops which was executed by FAO in cooperation with the Thai government (Saha, 1991). The main objective of this programme was to reduce the pesticide load. The economic threshold levels for cotton bollworms have been determined and *Trichogramma* eggs and NPV are being produced and used to control *H. armigera*. Cotton IPM programmes have also been initiated in Bangladesh, Myanmar, Indonesia and the Philippines.

All cotton-growing countries in Asia have policies to implement IPM in cotton. Most of the countries, however, do not have an institutional framework to undertake these activities (Anon., 1991d). Although considerable research has been carried out and IPM technology packages are available for pest control in many cotton-growing areas of the region, very few programmes have been implemented on a large scale.

BIOLOGICAL CONTROL OF SUGARCANE PESTS

Sugarcane is an important crop in several Asian countries. The important pests include stemboring caterpillars and grubs, sucking insects such as *Pyrilla*, whiteflies, scale insects and mealybugs, root-feeding grubs, rodents, the red rot disease and grassy weeds (Anon., 1991d). Most of the sugarcane pests are difficult to control with pesticides because they are well protected either by the dense canopy or because they feed in protected places either inside the stem or below the leaf sheath, or are in the soil. In spite of the fact that most sugarcane pests are not amenable to control with pesticides, chemical control has been used quite extensively in most Asian countries.

In recent years, mainly due to the inadequacy of pesticidal control, the mill owners and farmers have turned to alternative methods. The use of prophylactic applications of broad-spectrum insecticides is being slowly replaced by need-based use of selective insecticides. In India and Thailand, considerable attention is also being given to timing and method of application (Prachuabmoh *et al.*, 1988; ICAR, 1991).

It is interesting to note that some of the innovative approaches such as cultural manipulation and biological control methods for pest control in sugarcane have been pioneered in Asia. For example, excellent control of stemborers by augmentative releases of *Trichogramma* and of sucking insects by redistribution and conservation of natural enemies has been achieved (David, 1985; Mohyuddin and Hamid, 1988; ICAR, 1991; Mohyuddin, 1991). In spite of the successes, the adoption of these methods is still localised and pesticides continue to be used quite extensively.

India

The two notable examples of success in India are the control of the sugarcane top borer, *Scirpophaga excerptalia*, with an indigenous larval parasite, *Isotema javensis*, and the control of sugarcane pyrilla, *Pyrilla perpusella*, with *Epiricania melanoleuca*. In the case of *I. javensis*, the parasite has provided almost permanent control after initial inoculative releases made 15 years ago (Solayappan, 1987; Choudhary and Sharma, 1988). In the case of *E. melanoleuca*, since mass-production has been difficult, the approach has been to collect this parasite during the early part of the season and redistribute it so that it can build up in new fields. This parasite has now established in most sugarcane growing areas of the country. Inundative releases of *Trichogramma chilonis* and *T. japonicum* have been found to give effective control of borers. The technology for mass-production of *Trichogramma* spp. and their field release is also available (ICAR, 1991).

Pakistan

In Pakistan, similar success in biological control has been achieved in control of sugarcane stemborers by introducing different strains of *Apanteles flaviceps*, and by augmentative releases of *T. chilonis*. Sugarcane pyrilla has been checked by redistributing *E. melanoleuca* and by conservation of the egg parasitoid, *Parachrysocharis javensis* (Mohyuddin and Hamid, 1988; Mohyuddin, 1991). Integrated pest management in sugarcane requires strengthening of infrastructural support, including facilities for mass-production of biotic agents. It is felt that adoption of IPM technology for sugarcane, if convincingly demonstrated, should be easily done since in many parts of Asia sugarcane cultivation is directly or indirectly controlled by the sugar industry. In addition, with its dense canopy and long growing season, sugarcane offers an excellent ecosystem for the exploitation of natural enemies.

IPM IN HORTICULTURAL (FRUIT) AND PLANTATION CROPS

Horticultural and plantation crops, such as citrus, mango, apple, banana, rubber, oil palm, cocoa, coffee, tea, and so forth, are very high value crops in Asia. These crops are grown by large estates as well as smallholders. Tropical plantations are comparatively simple agro-ecosystems of mostly perennial monocrops where a dynamic equilibrium of biotic and abiotic factors prevails over a fairly large area (Liau, 1992). Only a few insect species are regular pests, while most are maintained at innocuous levels by biotic factors which are sustained by the agro-ecosystem. A breakdown of these suppressive factors can result in build-up of the pest population to outbreak proportions. Plantation crops in the humid tropics are particularly suited for IPM, whilst any other approach, particularly that involving only the use of broad-spectrum insecticides, can be disastrous (Wood, 1988).

IPM programmes for most fruit crops exist in several of the Asian countries. Pest management programmes for plantation crops, such as oil palm and cocoa, were developed several decades ago following the demonstration that pesticide use in these crops had actually *caused* the outbreaks of defoliating caterpillars by eliminating their natural enemies. This realisation led to the adoption of strategies for limited and highly selective application of pesticides (Djamin, 1988; Ho, 1988; Liau, 1988; Anon, 1991d).

IPM in Malaysian plantations has a good track record of success, especially in oil palm, cocoa, rubber and coconut. Pests have been better managed with minimal pesticidal input with reduced environmental damage, greater safety to operators and a higher degree of control that is also often more cost effective (Wirjosuhardjo, 1988; Liau, 1992). In Indonesia, a 15-year master plan for IPM on estate crops has been implemented since 1985 with the creation of the Directorate of Estate Crop Protection under the Ministry of Agriculture (Wirjosuhardjo, 1988). Biological control has been receiving attention for control of pests of fruits such as citrus, grapes, mango and apples in India (Singh, 1990b).

Coconut palm is particularly important in the Philippines, Indonesia, India, Sri Lanka, Thailand and Malaysia. Promising results with management of coconut pests such as the rhinoceros beetle, *Oryctes rhinoceros*, have been reported by combining the use of a baculovirus and fungi with cultural methods (Pillai, 1985; Kaske, 1988).

The successes in IPM on plantation and fruit crops have been mostly local. Pesticides are still widely used in the region. Furthermore, for a number of important pest problems, such as bunchy top of banana, the coconut beetle, *Scapanes australis*, and rodents in oil palm, there is no IPM, and substantial research efforts are required (Anon., 1991d). The current excessive pesticide use on plantations and fruits, unless corrected, is likely to compromise existing and potential IPM practices.

STATUS OF IPM IN INDIA

In India, crop losses due to all pests may range from 10% to 30% annually, depending on the crop and the environment. Annual crop losses due to pests in India have been estimated at Rs 60–70 billion (US$ 2.0–2.5 billion) (Jayaraj, 1989; Nagarajan, 1990). Pest control in India is still largely dependent on the use of synthetic chemicals. In most instances, spray schedules are based on calendars with little consideration of real necessity and little regard to various detrimental side-effects. Insect outbreaks have been greatest in those areas or crops where pesticide consumption has been the highest. In India, indiscriminate use of pesticides, particularly in cotton and paddy, is of such a magnitude that a reappraisal has become necessary.

Contributions by Indian scientists on the components of IPM systems are well documented. Biological control of pests, the development of resistant crop varieties, the manipulation of cultural practices to reduce pest incidence, and the use of botanicals such as neem are well-known practices in Indian agriculture. Additionally, crop diversity, intercropping, and the fact that most agricultural holdings are relatively small and intensively managed are all factors that favour the implementation of IPM at the farm level. Indian scientists and extensionists are now well aware of the problems that can result from overuse of pesticides, and the concept of an economic threshold for pesticide use is well recognised in the research community. However, in spite of these factors favouring IPM implementation, pesticide use continues to increase.

At present, the central government is giving about Rs 580 million as subsidies for distribution of pesticides under various crop schemes. In order to promote IPM, it has been proposed that this expenditure should be reduced substantially and the savings diverted to IPM schemes.

Pilot projects on IPM were initiated by the government in the 5th Plan (1975–80) in a modest way. Pest surveillance activities which were first started in 1980 soon after India became a signatory to the FAO Intercountry IPC Rice Programme have now been extended to all the major crops. In addition, the Ministry of Agriculture has established 25 centrally funded IPM centres in the country under the Directorate of Plant Protection, Quarantine and Storage to provide critical inputs needed for implementation of IPM programmes and to act as catalysts and model stations. These centres have been mandated to educate and create mass awareness of IPM among state extension functionaries and farmers through training and demonstrations. As these IPM centres can cover only about 5% of the total area under crops, it was proposed that apart from 25 IPM centres operated by the central government, 228 IPM centres (approximately one for every two districts), should be established by the state governments in the five years of the 8th Plan. Of the cost of these centres, 50% would be borne by the central government. It is envisaged that there should be about 550 such centres in the country by the year 2000.

Easily adaptable and economically viable IPM strategies have been developed for the control of major pests in rice, cotton, pulses, sugarcane, etc. Notable success in biological control of crop pests has been achieved through the conservation of biologically useful organisms through either selective use of pesticides or their avoidance. Release of biocontrol agents has successfully controlled pyrilla and top borer of sugarcane, mealybug of coffee, and lepidopterous pests affecting cotton, tobacco, coconut and sugarcane. A major achievement has been the development of mass-rearing technology for biotic agents such as *Trichogramma* spp., *Chrysoperla* spp. and nuclear polyhedrosis viruses (NPV) of *H. armigera* and *Spodoptera* spp. Spectacular success has been achieved in biological control of two aquatic *weeds*, viz., the water hyacinth, *Eichhornia crassipes*, and the water fern, *Salvania molesta* (Singh, 1991a,b).

The role of the private sector in popularising the adoption of IPM is very small, overall. However, a few private commercial insectaries in the country are now successfully producing biotic agents for growers, especially in southern India. A number of sugar factories are mass-rearing egg parasites and distributing these to farmers for control of sugarcane borers. In addition there are some socially conscious voluntary organisations promoting better agriculture and IPM.

STATUS OF IPM IN CHINA

China, the largest country in Asia, adopted integrated pest control with emphasis on prevention as its national policy on plant protection in 1975. This approach replaced the large-scale applications of chemicals in the 1960s and early 1970s which had caused a number of pesticide-related problems. Major IPM programmes have been developed for rice, vegetables and cotton. The main aspects of the IPM system in China are referred to as 'techniques, information, decision making and extension'. Training programmes have been intensified at all levels (Saha, 1991).

China has a national network of 1800 stations for monitoring the incidence of pests (ADB, 1987). This information is relayed from national plant protection monitoring stations to each province via a national broadcasting system. The technicians from local plant protection stations then travel to the field to advise the farmers on plant protection measures.

Much emphasis has been given to biological control as the major component of IPM in China (Liu and Piao, 1992). In the past two decades many biological control stations have been set up. Mass-propagation and release of a number of parasites and predators such as *Trichogramma* spp., *Chrysopa sinica*, *Anastatus* spp., *Rodolia rufopilosa*, etc. has been done over large areas. Ladybird beetles are manually collected from wheat fields every year and transferred to cotton for control of aphids.

Microbials, such as the nuclear polyhedrosis virus (NPV), *Beauveria bassiana* and *Bacillus thuringiensis* (*Bt*) were also sprayed over large areas. Biological control was given high priority in China's 6th and 7th 'Five-Year-Plans'. The area covered under biological control was

25.85 million hectares by the end of 1991. This represents a 200-fold increase over the total area covered in 1972 (Liu and Piao, 1992). In addition, *Bt* has been produced on a large scale. There are over 20 factories producing different strains of *Bt* which have been used for pests of maize, cotton, rice, vegetables, etc. In 1991, the area under *Bt* was estimated to be 1.39 million ha, while that under *Beauveria bassiana* was 800 000 ha. In addition, various viral preparations are also being made available to farmers. The first pilot plant was set up recently in the Hubei Province for production of NPVs (Liu and Piao, 1992).

NEEM IN PEST CONTROL

The Asian region is rich in 'botanicals' (pest control agents found in plants). A number of these have been found to have 'pesticidal' properties. Neem, *Azadirachta indica*, is the most promising of all the botanicals, and it has been used traditionally by farmers for pest control in the Indian sub-continent for centuries. Considerable research has been done on the bioefficacy and other aspects of neem, and neem-based preparations have been shown to be quite effective in controlling pests on various crops in India, Bangladesh, China, the Philippines, Sri Lanka and Pakistan (Ahmed and Grainge, 1986; Anon., 1989b; Saxena, 1989; Singh, 1990b). However, so far this has not led to any meaningful adoptable technology for the farmers. Until recently, most pesticides, including botanical pesticides, have had to have knock-down activity in order to attract the attention of users. This is now slowly changing with the realisation of the importance of IPM. Neem or other botanical pesticides are now being seen not as a total replacement of any particular pesticide, but rather as an important input of the IPM package to reduce dependence on synthetic chemicals.

A major problem associated with large-scale adoption of botanical pesticides is the lack of confidence in such products due to inconsistency of results. Neem derivatives require some degree of standardisation for biological efficacy. As neem extracts are photodegradable, better timing of applications is important. Another problem relates to farmers' perceptions. Many farmers in Asia are now aware of the beneficial effects of neem. Nevertheless, amongst the more affluent and enlightened farmers, the use of neem is still seen as a 'backward practice' (Anon., 1989b). Availability of good formulations would go a long way towards promoting the acceptance of neem as a viable alternative to the use of chemicals.

Neem-users' profile

The findings of a report on botanical pest control in rice-based cropping systems (Anon., 1989b) suggest that sophisticated commercial growers, especially of cash crops, are likely to be earlier adopters of botanical pest control materials than resource-limited farmers because:

- generally, cash crops have a greater incidence of pest outbreaks and growers, having invested in other purchased inputs, usually will have more to lose by not protecting their crops from pests, and
- growers of cash crops have been among the major innovators in the past, and thus are likely to be so in the future as well.

The findings also conclude that economics, safety and product availability will probably be the most important factors in farmer decision-making. Except for neem leaves, local availability of neem does not appear to be a factor in its usage, as other materials can be transported and even sold by pesticide dealers. Also, since most neem trees exist in marginal areas, there is not likely to be any competition between neem and agriculture.

On-farm preparation

The development of low-cost technologies for use of neem is important for resource-poor farmers. There is a need to promote on-farm preparation of neem insecticides. Farmers can easily prepare neem seed powder, neem oil and aqueous neem seed extracts themselves. Cottage industries should also be encouraged to take up production of neem insecticides based on simple alcoholic extracts. These can be obtained in a few steps and do not require sophisticated technology.

A number of commercial neem formulations are now becoming available on the Asian market. Neem formulations in India have now been brought under the Insecticide Registration Act, and at least five compounds have been registered for use in agriculture.

MANAGEMENT OF INSECTICIDE RESISTANCE

The development of resistance by several major pests to different groups of insecticides is a matter of great concern in many countries of

Asia. Saito (1988) has listed 13 species of major insect pests which have developed resistance to various insecticides in Southeast Asia.

Pesticide resistance management must be viewed as an integral part of an IPM strategy. The need for a sound resistance management strategy to ensure the long-term effectiveness of all classes of pesticides, especially synthetic pyrethroids, is very apparent and urgent. Insecticide resistance management (IRM) programmes have been initiated, especially on cotton and vegetables in several countries in collaboration with industry through the International Group of National Associations of Manufactures of Agrochemical Products (GIFAP) through their action committees: IRAC for insecticides, HRAC for herbicides and FRAC for fungicides. The other major group involved in this work is the International Organisation for Pesticide Resistance Management (IOPERM).

The most serious pesticide resistance problem in Asia concerns the diamondback moth, *P. xylostella*, and the American bollworm, *H. armigera*. Other major pests of concern are several species of aphids and *Spodoptera* spp. In rice, resistance problems have been found in BPH and the green rice leafhopper, *Nephotettix cincticeps*. Resistance in BPH to all the major groups of insecticides used in rice has been reported, including carbamates, organophosphates and pyrethroids (Whalon *et al.*, 1990). According to Saito (1988), since BPH migrates for long distances between Southeast Asian countries, and also to Japan, resistance is not only a domestic problem but also an international one.

The diamondback moth is considered virtually out of control in most parts of Asia because it has developed resistance to virtually all groups of insecticides. The moth has become a limiting factor to the production of crucifers in the Philippines, Indonesia, Malaysia, Thailand, Taiwan, India and other Asian countries (Evans, 1988; Magallona, 1988; Saito, 1988; Sinchaisri, 1988; Soekarna and Kilin, 1988; Tan, 1988). Resistance of *H. armigera* to various insecticides has been reported from India, Thailand, China and the Philippines (Sinchaisri, 1988; Mehrotra, 1989; Adalla, 1991; Cen, 1991; Wanboonkong, 1991). Though data is not available, it was most likely the cause of cotton crop failures in Pakistan, Bangladesh and Myanmar. In India, the serious outbreaks of *H. armigera* in cotton, pigeonpea and chickpea have caused great alarm. A very high degree of resistance to synthetic pyrethroids has been found in *H. armigera* populations in a number of states (Mehrotra, 1989; King and Sawicki, 1990; Phokela *et al.*, 1990; Armes *et al.*, 1992).

IPM AND THE GREEN REVOLUTION

The Green Revolution in Asia is associated with the spectacular increase in food production in the 1970s. The famines predicted for Asia in the 1960s, did not occur in the 1980s. In fact, most Asian countries are now self-sufficient in food grains. Food production, especially of rice which is the dominant crop in the region, has also kept pace with population increase (IRRI, 1985). The steady rise in rice yields during the 1970s came largely from irrigated farms, as semi-dwarf high-yielding rices replaced taller, photoperiod-sensitive cultivars, and pesticide and fertiliser (particularly nitrogen) use increased. With the introduction of Green Revolution technologies, insecticides were packaged as a production component input along with fertilisers, irrigation, credit and seeds. This packaged 'Green Revolution' technology brought with it the massive and calendar-based spraying of pesticides. The indiscriminate and injudicious use of broad-spectrum insecticides led to huge losses from resurgent secondary pests, as illustrated by the outbreaks of brown planthopper in almost all the rice tracts of Asia in the late 1970s. Insecticide contamination virtually eliminated rice–fish systems in many areas, and discouraged the practice of foraging for edible amphibians in rice fields (Garrity and Sajise, 1991).

The extensive use of high-yielding varieties (HYV) coupled with intensive use of pesticides has created a complex of plant protection problems (Litsinger, 1989). These include:

- increased cost of production,
- ecological shifts in pests,
- loss of biological diversity,
- depletion of genetic resources,
- environmental and health problems, and
- problems of pesticide resistance and resurgence of pests.

Modern plant breeding, with its emphasis on inbred, uniform strains has fostered a widespread trend towards large-scale monocultures. Whereas the traditional agro-ecosystem was genetically diverse, the emerging agricultural landscape is much more uniform. Most inbred strains of crop plants offer short-lived resistance to pests. Genetic erosion is depleting the gene base of our crop plants (Bramble, 1989). Besides the spread of HYV monocultures, the Green Revolution has encouraged the destruction of the soil, and yet the soil is the farmer's capital. Overploughing and poor irrigation practices are creating new dust bowls. Chemical residues and reduction in rotation damage soil structure and reduce available plant nutrients (Bramble, 1989).

Breeding for resistance to pests has been a vital aspect of the Green Revolution for the last two decades. The evolution of biotypes which break the resistance has, however, become a serious concern. Many new varieties, which are essentially 'high-response' varieties, are also of short duration and mature early, enabling the farmers to grow two or even three crops a year. However, whereas traditional varieties are tolerant to rainfed environments typified by alternating periods of drought and floods during the rainy season, modern varieties yield poorly under desiccation or submergence.

Continuous cropping and loss of rotations have accentuated pest problems. Other than susceptibility, the change in insect and disease micro-environments may have contributed to pest outbreaks. For example, the short stature, highly tillering new rice varieties contributed to outbreaks of the brown planthopper in some Asian countries (Pachico and Schoonhoven, 1989). The resurgence of pests has become much more common. The continued use of broad-spectrum, synthetic insecticides has made conservation of natural enemies impossible.

During the 1980s, a number of sustainability attributes became serious concerns. First there appeared to be significant degradation of the resource base that supported irrigated rice. Rice and wheat yields were observed to have plateaued in several countries in Asia during the 1980s and even declined in several locations during the decade. There was also a decline in the real income of farmers as they began to experience stagnating yields and low grain prices, while labour and input costs escalated.

There is no doubt that the Green Revolution's fertiliser-responsive rice and wheat varieties have had a major impact on production. However, their adoption by resource-poor farmers has been a matter of great concern. The need for complementary inputs of fertilisers and pesticides imposed a capital requirement that was feared to have put the new technologies outside the reach of subsistence farmers (Pachio and Schoonhoven, 1989). The new varieties were selected for performance in favoured conditions of high fertility, timely irrigation and pest control situations that often failed to correspond to the reality faced by poorer farmers. The new varieties also frequently increased risk due to increased varietal susceptibility to diseases and pests.

Research in the post-Green Revolution period

The debate about the pros and cons of the Green Revolution's fertiliser-responsive, semi-dwarf wheats and rice has had considerable influence on research in the post-Green Revolution period. The approach now must be to limit the negative ecological impact of agricultural chemicals while maintaining the production gains. The emphasis in breeding for resistance has already shifted to developing varieties with broad-based horizontal resistance to pests. Plants must be selected for pest resistance under high pressure levels and usually without chemical control or irrigation and low levels of fertility, to generate improved pest resistance and thereby reduce risk without requiring an increase in the use of agrochemicals.

Conservation of natural enemies by eliminating or restricting the use of broad-spectrum insecticides in tropical agro-ecosystems is now recognised as the most important aspect of a sound agricultural management strategy. The use of biological diversity is another aspect of the current strategy. The unreliability of varietal resistance and chemical control has given a new respectability to the intercropping approach which can mimic a diverse ecosystem. Finally, research needs to take a greater responsibility in resolving the socio-economic constraints of IPM. As pointed out by Goodell (1989):

> IPM researchers working within the context of the Green Revolution must accept that all technology is contingent upon the socio-economic (including institutional) environment in which it is used.

EPILOGUE

The situation with regards to the development and implementation of the integrated pest management (IPM) approach to pest control in South and Southeast Asia can be summed up as follows:

- Pest control in Asian countries is still largely dependent on the use of pesticides. In many countries pesticide consumption has actually increased in the past decade.
- Pesticide subsidies in one form or another continue to be part of the agricultural policy in most of Asia and the information environment still favours the increasing use of pesticides by farmers.

- The adverse effects of pesticides, however, are now well recognised and appreciated. New approaches are being developed and advocated.
- Ten countries at present have pesticide legislation to control the production, import, export, handling and use of pesticides. The main problem with pesticide regulations in Asia is in their enforcement.
- IPM now exists in one form or another with varying degrees of sophistication in most Asian countries. Major efforts have been directed towards food crops like rice, maize and vegetables; to commercial crops such as cotton and sugarcane; and to other high-value horticultural and plantation crops.
- IPM has been adopted as the official policy in most Asian countries. Government surveillance and forecasting programmes exist in China, India, Indonesia, Malaysia, Korea, Pakistan, the Philippines and Thailand.
- IPM approaches have succeeded in reducing the use of broad-spectrum pesticides and a number of studies have shown IPM to be more economical than conventional methods based on the use of chemicals. However, adoption of the practice of IPM at farm level still encounters several difficulties.
- The focus has shifted from pest control to pest management, from varietal resistance to tolerance, and from yield advantage to yield stability.
- A striking change from the past is the emphasis now being placed on use of biological control agents in developing IPM strategies. Although various novel approaches, including the possible use of transgenic plants, are becoming fashionable, pest control in the next decade in tropical Asia will continue to depend overwhelmingly on making the best use of conventional methods, including conventional pesticides, as part of IPM.

Pests will continue to be a major constraint and a serious threat to yield stability. Increases in crop yields in many countries of Asia have reached a stage of rapidly diminishing returns. The initiative for development of IPM will have to continue to come from researchers and policy-makers. As far as the farmers are concerned, ideological reasons alone are unlikely to change their attitude towards chemical control. Similarly, chemical companies are unlikely to stop production and distribution of broad-spectrum pesticides by their own initiative. Governments must take the lead by introducing measures that will make chemical control less attractive, by legislation, registration and even taxation. All pesticide subsidies must be removed and the resources diverted to funding IPM research, to education and to the improvement of extension services.

Concern continues to rise over the continued use of certain pesticides. A number of pesticides amongst the 'dirty dozen' which have been banned in the developed world are still being produced and sold in Asia. The need for IPM in tropical Asia is today greater than ever before.

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3 Review of IPM in South America

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The sub-continent of South America includes 12 independent countries and two European colonies located south of Panama, between 13°N and 55°S latitude. This is a diversified region, ranging from the dominating tropical lowland in the north to the temperate tip in the south. Considerable diversity is also observed from east to west due mainly to differences in altitude. The eastern section is more uniform, with altitudes very rarely exceeding 1000 m above sea level. The western section ranges from a coastal Mediterranean type of climate to the cold inland of the Andean mountain chain, where altitudes reach over 6000 m.

The total area of this sub-continent is about 17 830 000 km^2, equivalent to almost twice the size of the USA, or about 12% of the total global land area. Roughly 47% of this area corresponds to the Brazilian territory, located in eastern South America. It is rather difficult to state exactly how much of South America can be considered arable land, because the agricultural potential of a large proportion which is still not inhabited is poorly known. However, it is estimated that only about 5% of the total area is presently cultivated, that about 20% is used for livestock production, and that over 90% of the total area can be used for either purpose.

Parts of this large sub-continent already represent important food-producing regions that supply a large proportion of world needs. Considerable potential still exists for a more significant participation of South America in the world agricultural market, especially in relation to crops that are well adapted to this part of the world. Integrated pest management (IPM) will play a major role in allowing the expression of the full potential of each crop to be realised, while conserving the natural yield capacity of the corresponding ecosystems.

Integrated Pest Management in the Tropics: Current Status and Future Prospects
Edited by Annalee N Mengech, Kailash N. Saxena and Hiremagalur N. B. Gopalan

AGRICULTURAL OVERVIEW OF SOUTH AMERICA

Agriculture is still the main economic activity in South America, despite the recent significant industrial development of some countries in the region. The rural population ranges from about 14% of the total population in Argentina to about 53% in Paraguay. Income from agricultural activities ranges from 9% of the gross income in Brazil to over 27% in Paraguay (IICA, 1991). In such a diverse sub-continent, there is a considerable cultural diversity, represented by the influx of peoples of different origins. Adapting to the abiotic factors prevailing in different regions, South American peoples have domesticated some important crops which today are grown worldwide, such as potato, tomato, cassava, peanuts and pineapple. They have imported from around the world other crops fitted to localised conditions, such as coffee, maize, rice, wheat, soybean, sugarcane, citrus, etc., developing or adopting unique agricultural practices.

Because of the general ease of communication and through the efforts of international organisations which operate in the region, many South American countries today show similar patterns of agricultural development, geared mostly to the recent need to increase agricultural output in order to cope with their growing populations, and to comply with the payment of foreign debts and related external expenses.

The main cash crops grown in South America are coffee, maize (corn), wheat, soybean, sugarcane, cotton and fruits, which prevail differently according to local ecologies. Livestock (cattle, goats and sheep) rearing is also important in most countries. Until recently, coffee was by far the most important crop in at least two countries, Brazil and Colombia. The value of this crop fluctuates according to the international market prices, but regardless of its price, coffee is still one of the most important crops.

Maize (*Zea mays*) and cotton have been extensively grown in several countries of the sub-continent, although the area under cultivation in cotton has been tremendously reduced since the introduction of the boll weevil, *Anthonomus grandis*, into Brazil in 1983. Nevertheless, this country continues to be the largest cotton producer in South America and the sixth largest producer in the world. Wheat has long been an important crop in Argentina, which has historically supplied a considerable part of the international market. Chile has also been an important wheat producer, although the total amount produced is consumed within the country. In Brazil, the cultivation of this crop has recently expanded considerably, and varieties have been developed to cope with warmer and more humid weather.

Sugarcane is most important in tropical and sub-tropical areas of eastern South America, where it has been used primarily for sugar and alcohol production. In Brazil alone, nearly 4 million hectares are cultivated under sugarcane. It is also an important crop in Peru and Argentina. Soybean cultivation has increased markedly in southern Brazil, Argentina, Paraguay and Bolivia during the last 30 years. Today, over 6 million ha in South America are under cultivation with this crop, which is used locally for the production of cooking oil and for exportation of raw beans. The income resulting from exportation of soybean corresponds to almost 30% of the total Brazilian agricultural exportation.

Fruits also constitute important crops in South America. Of special significance is the production of citrus in Brazil, the second largest world producer, as well as apples in Argentina and several temperate species in Chile. In addition, many tropical species have received increasing acceptance in the international market, such as indigenous guava and exogenous mango, kiwi and star fruit.

Cattle raising in South America is done mostly in Argentina, Brazil and Uruguay. Meat production in these countries has supplied the local market and generated a surplus for export. Goat and sheep production is most important in the Andean region and in the southern part of the continent.

Regional agricultural reorganisation

In addition to the external influences reported previously, important recent developments related to the formation of regional commercial groupings are leading to considerable changes in the relative importance of different crops and livestock in South America. With the progressively reduced customs for the countries of each such group, competition will have an important bearing upon the regional, spatial and temporal distribution of crops and livestock in the region, as has happened in other parts of the world.

The first of these regional groups, known as the *Andean Pact*, and integrating Bolivia, Colombia, Ecuador, Peru and Venezuela, established a zone of free commerce in 1992, and began to have unified customs as of 1993. The second, known as *MERCOSUL* and integrating Argentina, Brazil, Paraguay and Uruguay, began to operate in

January 1995. Initial activities include as an important component, the joint generation of agricultural technologies most appropriate to the region.

The establishment of these regional commercial groups will facilitate the trade of commodities and industrialised materials, and should lead to increased demand for better quality agricultural products. This will include products free of chemicals. IPM will play an important role here in reducing the pesticide residues in the food produced.

Level of technology adoption

The different countries of South America have experienced an uneven adoption of modern technology, due to varying degrees of access to international markets, circumstantial financial realities, the differing availability of infrastructure and other factors. While all countries have, to some degree, adopted the use of machinery and chemical inputs, especially for the production of exportable goods, most countries have areas where agriculture is practised for subsistence purposes and where cultivation practices have been basically the same for many years. Given the growing pressure for increased production to supply local and external markets, considerable environmental degradation has been verified in over- or under-explored regions, commonly resulting in natural resource depletion.

Of great importance in this sense is the recent widespread cultivation of soybean in southern South America, which immediately resulted in increased forest cut-down, soil erosion and other undesirable developments. More intensive cultivation systems and requirements for near-zero economic damage of exportable fruits and other goods have also frequently resulted in undesirable environmental pollution in Chile, Argentina and southern Brazil. Those stages once thought unavoidable in a development process are now being questioned by public opinion and are influencing the way local governments direct the development processes.

Safer agricultural production is in demand

Regardless of the under-development of extensive portions of South America, the generally effective communication system has promoted a general consensus on the need to conserve natural resources. The impact of the recent United Nations-sponsored meeting in Rio de

Janeiro cannot be overemphasised, especially in relation to professionals working in agricultural research and development. Local radio and television networks in some countries commonly present themes related to environmental conservation, which influence a considerable part of the population. However, the region is lacking in consistent consciousness-building programmes and alternatives directed specifically to the rural (largely illiterate) population, a great proportion of whom struggle to survive and who quite often, as a consequence, over-exploit the natural resources at hand.

Generalised concepts related to environmental quality as affected by agricultural activities are absorbed from the international ecological outcry and commonly used in all sorts of consciousness-raising programmes. However, very few hard field data exist regarding degradation factors in the South American region, especially as regards the levels of pollution and contamination and their effects on biological processes. Those data are urgently needed to make such programmes more effective.

TRENDS IN PESTICIDE USE

The use of pesticides in South America has been considerable, the amounts varying depending on the size of the country, the types of crops grown and that country's access to international markets. Pesticide sales more than doubled in the region between 1976 and 1980 (IRL, 1981). Pesticide use in Latin America corresponds to about 10% of the global pesticide market, and Brazil accounts for nearly 50% of pesticides used in Latin America. For some countries, the actual usage data for pesticides is rather unclear, especially because of unofficial introductions into those countries from their neighbours. This is apparently the case with *Bolivia* (SEMTA, 1990), where pesticides were first used in the 1960s, coinciding with the massive colonisation of the Bolivian tropics after the Agrarian Reform. From 1966 to 1975, the consumption of pesticides in Bolivia jumped from less than 200 tonnes to over 1300 t, almost all of which was composed of chlorinated pesticides. In 1988, the official total amount of imported agrochemicals (probably mostly pesticides) was over 5600 t (SEMTA, 1990). The data available are not clear, but most of that amount probably corresponds to formulated products. Considering the extensive cultivation of soybean in Bolivia in the last few years, it is expected that the volume of pesticides used in that country will have increased considerably.

Until recently, *Brazil* was the fifth largest world pesticide consumer, after the USA, Soviet Union, France and Japan. It has been considered as the largest potential market for pesticides, because of its wide territory and the relatively high importance of agriculture to the country's economy. However, the pattern of pesticide use in Brazil has drastically changed in the last 20 years. The yearly consumption rose steadily until the early 1970s (Figure 3.1a), when the economy was booming. During

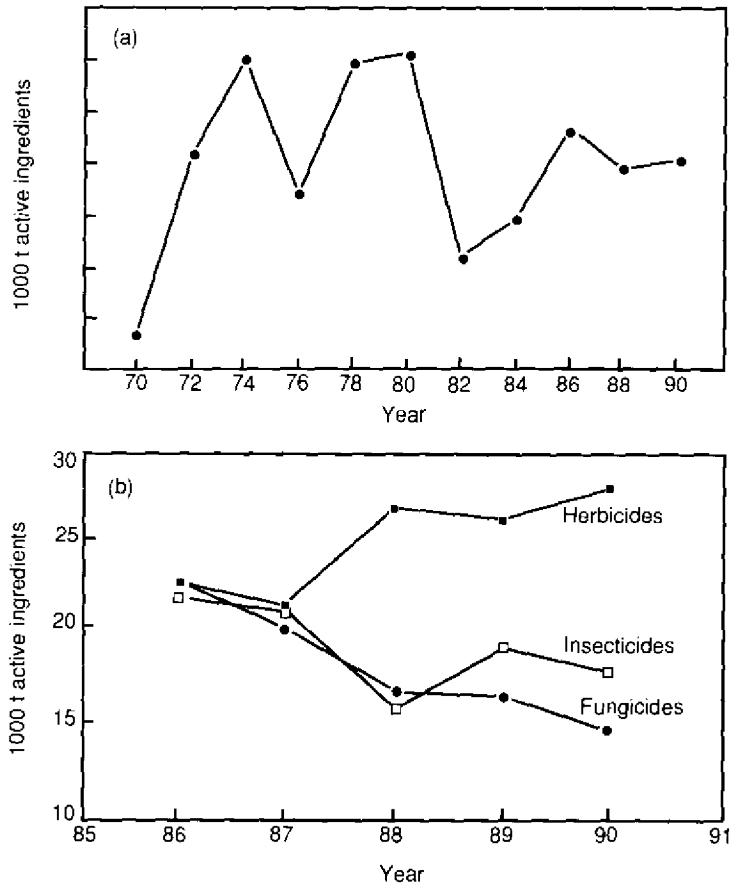

Figure 3.1. Pesticide use in Brazil. (a) Total pesticide use in 1970–1990; (b) Use of main classes of pesticides in 1986–1990
Sources: Alves, 1986; ANDEF, 1991.

that decade pesticide use remained high because of governmental incentives promoted by credits and subsidies. Subsequently, a period of crisis occurred in the early 1980s, with a consequent reduction in pesticide utilisation to approximately half of what it was in the previous decade. Since then, a slight increase in use has occurred, but a tendency towards stabilisation has been observed.

Since 1986, the use of fungicides and insecticides has decreased in Brazil (Figure 3.1b). The main reasons for this pattern are probably an increased environmental awareness, reduced subsidies and growers' decapitalisation. These basic factors have resulted in the generation of new, alternative technological options, permitting the more limited use of chemicals or their replacement by other means of pest control. The new options include the more judicious use of pesticides, availability of more efficient compounds, development of new plant varieties resistant to diseases, and use of biological control (Flores *et al.*, 1992).

On the other hand, the use of herbicides has been increasing in Brazil. This is probably due to economic reasons. Weeding normally requires a considerable input of labour, which frequently leads to local scarcity of manpower in areas of agricultural expansion. This obliges growers to adopt techniques which are less labour-dependent, such as control of weeds with herbicides. In addition, new rural labour laws and social conditions in Brazil have contributed to a rural exodus after the 1970s, aggravating the problem of manpower scarcity.

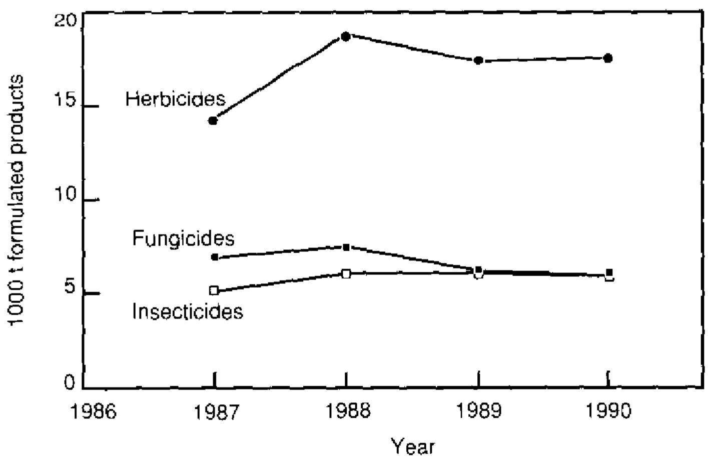

Figure 3.2. Pesticide use (formulated products) in Argentina in 1989–1990 Source: CASAFE, 1990.

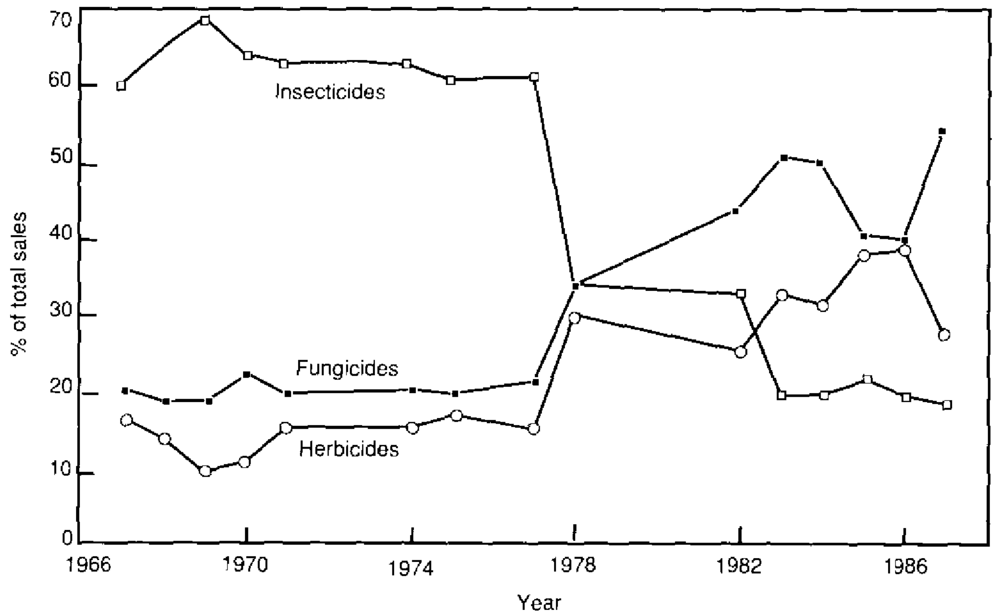

Figure 3.3. Percentage of sales of the main classes of pesticides used in Colombia in 1967–1987
Source: Bellotti *et al.*, 1990.

In *Argentina*, the use of the three classes of pesticides has remained at practically the same level since 1987 (Figure 3.2), as observed for Brazil.

In *Colombia*, pesticide sales have increased slightly since the mid-1970s (Bellotti *et al.*, 1990). Insecticide sales corresponded to approximately 60% of the total in the 1970s (Figure 3.3). They reached a peak of 15 000 tonnes of active ingredient in 1977. With the implementation of IPM programmes emphasising the use of biological control, sales of insecticides decreased drastically, corresponding to only 20% of pesticide sales in 1987. Insecticide sales now correspond to about 4000 t of active ingredients a year.

The consumption of pesticides in *Peru* has shown a very slight increase in the last decade, rising from 1700 t of active ingredients in 1981 to 2100 t in 1991 (German Diaz, pers. comm.).

On a cropwise basis, soybean, fruit trees, sugarcane, wheat, coffee and cotton are the crops, in decreasing order, with the largest demand for pesticides in Brazil (Thomas, 1988). More than 50% of the insecticides consumed in that country are applied to fruits, cotton and

Table 3.1. Pesticide consumption in South America

Country	Consumption(t)[1]	Year	Reference
Argentina	6000[3]	1990	CASAFE, 1990
Bolivia	5600[2]	1988	Semta, 1990
Brazil	22 000[3]	1986	Alves, 1986
	18 000	1990	ANDEF, 1991
Colombia	15 000[3]	1977	Bellotti *et al.*, 1990
	4000[3]	1992	
Peru	2100	1991	C. Diaz, pers. comm.

[1]In tonnes of active ingredients.
[2]Total agrochemicals used, mainly pesticides.
[3]Insecticides.

soybean; almost 75% of the fungicides are used on wheat, horticultural products and fruits; and more than 50% of the herbicides are used on sugarcane and soybean.

Cotton has usually been cited as a classical example of a crop requiring heavy use of pesticides. Recent successful IPM programmes for this crop in several countries have considerably reduced the need for insecticide applications (Bellotti *et al.*, 1990). All over South America today, soybean receives the largest amount of insecticides. Large monocultures in Brazil, Argentina and Colombia, especially of soybean, rice and sugarcane, have resulted in increasing herbicide consumption.

The implementation of MERCOSUL will influence the level of pesticide use in the countries involved. National regulations about registration and use of pesticides, involving chemical and biological products, will have to be harmonised in the region, and it is expected that the more strict laws in some countries may prevail and be adopted by the whole region. In some countries, persistent chlorinated hydrocarbons and mercurials are still allowed, and if a free regional commerce is to be adopted, the use of such chemicals will have to be banned or controlled more closely. Table 3.1 summarises data on pesticide use within the region.

INSTITUTIONAL ASPECTS OF IPM DEVELOPMENT AND IMPLEMENTATION

In most countries in South America, national agricultural research institutions (NARS) generally dominate the activities related to IPM development and implementation. In general, these are large organisations primarily involved with applied work, and with a research mandate over the entire country. On the one hand, this may facilitate widespread implementation, but on the other hand, given the ecological framework of IPM, the involvement of regional institutions is indispensable in order to avoid overlooking details which determine the success or failure of any given programme.

Agricultural colleges and local government-owned research institutions/systems also play a major role in those countries active in agricultural research. Thus, several state universities in Brazil have been deeply engaged in IPM development. The University of the State of São Paulo (UNESP) at Jaboticabal is the leading Brazilian educational institution in this area. CEMIP (Integrated Pest Management Centre), an organisation attached to that campus, has been working on cotton and citrus, and has played a major role in implementing IPM at the growers' level (Gravena *et al.*, 1987).

Biocontrol agent production

A number of non-governmental organisations (NGOs) operate in South America. These organisations have also been involved in the implementation of low-input technologies, which not only relate to pest management but to all aspects of agriculture.

Private enterprise has played a progressively major role in implementing IPM programmes, by making available the necessary components. For example, the number of private laboratories which produce natural enemies has increased considerably in the last few years, following the same pattern observed in other parts of the world. Over 20 private laboratories produce parasitoids (especially *Trichogramma*) in Colombia for commercial purposes. These parasitoids are sold internally in Colombia or exported to other countries. The natural enemy business has become so important that the Colombian government established appropriate rules to assure a quality control of the organisms produced. This control is done through the ICA (Colombian Agricultural Institute) (Garcia, 1990). In addition, most sugar mills maintain a permanent production of parasitoids to be used in the control of the sugarcane borer. Laboratory production of *Diglyphus begini* is also an important endeavour in the control of leafminers on different crops.

A few laboratories for natural enemy production are also found in

Brazil. The oldest ones were constructed to produce the fungus *Metarhizium anisopliae* to be used in the control of planthoppers on sugarcane. The parasite *Cotesia flavipes* has been extensively produced in most sugar mills in Brazil for the control of the sugarcane borer. In the northeastern part of the country, the production of *Trichogramma* is now very important for the control of the leafminer/fruit borer in thousands of hectares of tomato plants. Another important activity is the large-scale production of *Baculovirus anticarsia* for the control of velvetbean caterpillars on soybean. The production of this virus was done only by EMBRAPA/CNPSO until recently, but now there are four private companies that produce and commercialise it using basically the same production technologies. This constitutes a good example of technology conveyance to the private sector, where a formal contract has been signed and royalties are paid to EMBRAPA, which uses those resources to support research activities.

In Peru, 23 laboratories presently mass-produce natural enemies for field releases. The beneficials produced are the native *Trichogramma* spp. and several other parasites, predators and pathogens.

Twelve commercial laboratories produce entomophagous insects in Venezuela. The natural enemies and pathogens produced are *Trichogramma* spp., *Telenomus remus*, *Bracon* spp., *Metagonystilum minense*, *Metarhizum anisopliae*, *Beauveria bassiana* and *Nomureae rileyi*. One laboratory attached to a growers' organisation produces entomopathogens (Linares, 1990).

In Paraguay, growers' cooperatives are presently producing large amounts of *Baculovirus anticarsia* for use on soybean. Many other cases of mass-production of natural enemies for experimental purposes or for more restricted use in pest control could be mentioned. Therefore, one could say that the 'natural enemy business' is a very progressive endeavour in South American countries.

IMPACT OF REGIONAL IPM PROGRAMMES

This section considers crops for which significant IPM programmes have been used. Most of the cases mentioned refer to programmes developed during the past 10 years, and which have reportedly had an important impact on the amount of pesticides used.

Alfalfa

Argentina

Alfalfa is the main leguminous crop cultivated in Argentina, where it occupies about 5 million hectares annually. The heavy damage caused by the introduction in 1969 of the alfalfa aphid, *Acyrtosiphon pisum*, resulted in the development of an IPM programme against this and other pests. Currently, the most important pests of alfalfa are four aphid species, defoliating caterpillars and weevils.

The practices used for IPM require the recognition of pests and natural enemies. Host plant resistance, use of *Bacillus thuringiensis* (*Bt*) or reduced doses of insecticides for control of caterpillars, and introduction of parasitoids (*Aphidius* spp.) for the control of green and blue aphids are important aspects of this programme.

The use of resistant plant varieties has led to a reduction of two to three insecticide applications against aphids. In addition, it has been found that the use of *Bt* and reduced doses of pyrethroids and other selective products for lepidopteran larval control have not significantly affected the diversity of natural enemies, which help to keep other pests under control (J.R. Aragon, pers. comm.).

Citrus

Argentina

The citrus IPM programme was initiated in 1977. The introduction and conservation of natural enemies are of considerable importance in this programme. When pests surpass the respective economic thresholds, only selective pesticides are used.

Citrus IPM was responsible for a reduction in the number of pesticide sprays to only one or two against diaspidid scales and for promoting the use of more selective pesticides, such as emulsion oil. In northwestern Argentina, the method has generated savings of US$ 2 million per year in chemical treatments (A.L. Terán, pers. comm.).

Brazil

Citrus production in Brazil is concentrated in the State of São Paulo, with a planted area of almost 1 million ha corresponding to about 80% of the total national production (Pellegrini, 1990). The most important pests of this crop are the 'leprosis' mite, *Brevipalpus phoenicis*, and the citrus rust mite, *Phyllocoptruta oleivora*. The former species is of particular interest in São Paulo, where it is a vector of the 'leprosis' virus. Scales and fruit flies are other pests of widespread occurrence and of localised importance.

Citrus IPM tactics in Brazil are based on the adoption of economic injury levels for insecticide/acaricide sprays and on the maintenance of weeds between plant rows to provide shelter and reproduction sites for natural enemies. Obviously, this practice requires careful and frequent scouting in the field. The CEMIP/UNESP has provided a significant contribution to this activity since 1986, assisting growers in IPM implementation.

In the 1970s, 20 pesticide applications were made annually. Of 170 orchards monitored recently, the average number of annual sprays is now about 4.6 (S. Gravena, pers. comm.). This number will continue to decrease as more growers adopt the programme, because very often mismanaged orchards have negatively affected the effectiveness of IPM in adjacent orchards. It is considered that only one or two pesticide applications might be sufficient in many cases. In addition to savings in insecticide/acaricide use, further savings are expected from the reduction in herbicide use. The goal of this programme is to involve at least 6000 growers, i.e. 30% of the total growers in the state.

Cotton

Brazil

Traditionally, cotton is one of the crops that has received the largest amount of pesticides worldwide. Until recently, up to 40 insecticide applications were done yearly in Brazil against two key pests of this crop, the tobacco budworm, *Heliocoverpa* (*Heliothis*) *virescens*, and cotton leafworm, *Alabama argillacea*.

The first important cotton pest management programme started in Brazil in 1979, as a result of the participation of research entomologists, extension agents and farmers in the First Brazilian Meeting on Cotton Pest Control (Ramalho, 1994).

An economic assessment of IPM in cotton showed that a reduction of 50% in the amount of pesticides used, or a 58.3% reduction in the cost of pest control could be achieved. However, after the introduction of another serious pest, the boll weevil, *Anthonomus grandis*, in 1983, the IPM strategies employed earlier have had to be revised.

The cotton IPM programme used in Brazil today focuses on the following approaches:

- use of rapid fruiting and early-maturing varieties, particularly suitable for boll weevil control. This practice allows avoidance of the heavy mid- to late-season pest populations;
- biological control by parasitoids, predators and especially pathogens. This tactic is particularly concerned with the exploitation of naturally occurring insect diseases and applications of microbial insecticides;
- area-wide uniform planting periods;
- cotton-free period;
- destruction of infested squares, bolls and alternate hosts;
- early and uniform stalk destruction;
- use of trap crops;
- crop rotation;
- climatic control of boll weevil larvae by providing high temperatures and low humidity to the soil during the growing season, by varying plant spacing;
- judicious use of chemical control, based on scouting of pests and natural enemies and adoption of economic thresholds; dose reduction and use of selective pesticides are also recommended.

With the adoption of IPM in the early 1980s, only one or two insecticide treatments were necessary for pest control. However, after the introduction of the boll weevil, the number of treatments required increased to four or five.

About 70% of farmers in the state of São Paulo, the main cotton producer in Brazil, apply the basic principles of IPM for cotton production (Ramalho, 1994). However, most farmers neither scout their fields nor use economic thresholds to support their decisions concerning applications of control measures, especially the use of pesticides. Therefore, much more remains to be done by extension agents for a full IPM adoption. The fact that cotton is one of the most traditional Brazilian crops constitutes an important constraint for full adoption of IPM. Farmers are conservative and it takes time for new technologies to be adopted by them.

Colombia

The main cotton pest in Colombia is the cotton bollworm, *H. virescens*; this pest is also important on several other crops. The cotton IPM programme in this country has centred on the use of an egg parasitoid, *Trichogramma pretiosum*, produced commercially for periodical releases. Other management strategies in use include post-harvest stalk destruction, restrictions on the allowed planting period and no insecticide use until 70–80 days after planting.

Chemical control has been greatly reduced since implementation of the IPM programme. ICA (Colombian Agricultural Institute) reported that the number of insecticide sprays in cotton decreased from more than 20 to only two or three a year. The control cost now represents only 3.5% of what it was formerly when chemicals were used extensively on this crop (Garcia, 1990). An evaluation conducted in 1988 in Valle del Cauca indicated that IPM was used in practically all cotton fields, corresponding to an area of 26 000 ha. In the municipality of Zarzal, the number of spray applications dropped from between 12 and 20 in 1974–75 to 1.2 in 1981 and 0.8 in 1984 in over 6000 ha of cotton fields (Fulvia Garcia, pers. comm.).

In addition, considerable ecological benefits have been generated; several species ranked as primary pests in the past are now considered of secondary importance. However, the presence of the destructive boll weevil in Valle del Cauca as of April 1992 (Fulvia Garcia, pers. comm.) may impose a new challenge to this management programme. Additional research may be necessary to integrate the practices now in use with the tactics that will be necessary for control of this newly introduced pest.

Paraguay

Although in many countries cotton is one of the crops that consumes the largest amounts of pesticides, in Paraguay few applications are required annually because of the effective presence of native natural enemies of the prevailing pests. Whereas in many Latin American countries as many as 35 insecticide applications can be made annually, normally only two treatments are necessary in Paraguay, corresponding to 15% of the total cost of control (Servian de Cardozo, 1990).

The recent introduction of the boll weevil (*Anthonomus grandis*) to the country will probably require a review of the IPM strategies, based on the large amounts of insecticides that are normally used to control this pest in other countries.

Peru

As early as 1934 the concept of cotton IPM had been proposed in Peru, as an integrated and harmonious use of cultural, biological, legal and chemical control. Ironically, the case history of cotton pest control in the Canete Valley of Peru is used today as an example of what has been termed the 'pesticide syndrome' by Doutt and Smith (1971), to describe the phases through which patterns of crop protection tend to pass before agro-ecological balance is achieved. Crisis and disaster phases were reached in the 1950s, after the primary pests of cotton became resistant to the commonly used chlorinated pesticides. Organophosphates were then put into use, but failed to provide adequate control, resulting in more frequent pesticide applications and the consequent upsurge of secondary pests, especially *Argyrotaenia sphaleropa* and *Platynota* sp., which occurred because of the destruction of their natural enemies (Beingolea, 1989).

During this period, the cotton industry in the Canete Valley suffered its most serious crisis, which ultimately led to the development and adoption of an efficient IPM programme. This programme consists of the improvement of the cultural methods used; a ban on perennial cotton cultivation; re-introduction of natural enemies; and judicious use of selective pesticides. These changes were made into legal regulations of the Ministry of Agriculture, and resulted in a rapid and striking reduction in the severity of cotton pests (DeBach, 1974).

Venezuela

The main cotton pests in Venezuela are the boll weevil, *A. grandis*, and the lepidopteran *Sacadores pyralis*, *Helicoverpa* spp. and *Spodoptera* spp. IPM of these species consists basically of the use of a few cultural measures (control of alternative weed substrates and destruction of dropped floral structures), restricted planting period, releases of *Trichogramma* spp., *Telenomus remus* and *Bracon* spp., and judicious use of insecticide treatment against boll weevils (Linares, 1990). Although this programme has reportedly been in common use in Venezuela, no data on its impact and resultant savings have been seen.

Soybean

Argentina

The soybean IPM programme, focusing on control of defoliating caterpillars and green stink bugs (*Nezara viridula*) was initiated in Argentina in 1984. The introduction and conservation of established natural enemies is an important element, and, since the implementation of the programme, there has been a reduction in the number of insecticide treatments from two to three per growing season to an average of 0.3 treatments. In the northwestern part of Argentina, this corresponds to a savings of US$ 1.2 million per year in pesticides and application costs (A.L. Terán, pers. comm.). Another recent report (Aragon, 1991) states that, with the adoption of this programme, it is possible to reduce by 50% the number of insecticide applications.

Brazil

Commercial soybean cultivation started in southern Brazil in the early 1950s. Today, the crop is grown on more than 8 million ha spread over sub-tropical and tropical regions. Pest control in this crop represents a considerable expenditure, each spraying corresponding to about 10% of the total production cost (Roessing, 1984).

The main pests of soybean are the velvetbean caterpillar, *Anticarsia gemmatalis*, and the stink bug complex of pod and seed suckers (*N. viridula*, *Piezodorus guildinii* and *Euschistus heros*). Most of the insecticides used in soybean are directed against the first species. In response to the overuse of insecticides, an IPM programme has been developed. The control measures adopted are based on monitoring of pest populations and natural enemies by a sampling procedure that involves counting insects falling onto a cloth placed underneath the soybean plants. The numbers of insects are compared to the economic injury levels previously defined for the key insect pests.

IPM in soybean comprises the combined use of the following tactics (Iles and Sweetmore, 1991):

- use of trap crops for stink bugs;
- early planting to avoid thrips, which are vectors of viral diseases;
- soil management to reduce soil-borne fungal diseases;
- adequate soil preparation to reduce soil insect pests;

- use of varieties resistant to stink bugs, foliar diseases and nematodes;
- use of selected insecticides recommended by a Design Committee;
- use of a nuclear polyhedrosis virus (NPV), *Baculovirus anticarsia*, against *A. gemmatalis*.

About 40% of farmers have adopted the programme, with savings of over US$ 200 million annually due to reduced use of insecticides, labour, machinery and fuel (Iles and Sweetmore, 1991).

Five insecticide applications per season were done for soybean pest control in the early 1970s. With the implementation of the IPM programme, only one or two yearly applications are now required. In some areas, the use of insecticides has been completely abolished (Dossa *et al*., 1987). The strategy responsible for the success of the whole programme was the use of *B. anticarsia* for the control of *A. gemmatalis*. This virus was identified in 1971 as an effective mortality factor of the pest. In 1980/81, *in vivo* production of the virus was initiated by EMBRAPA/CNPSO (Empresa Brasileira de Pesquisa Agropecuria/Centro Nacional de Pesquisa de Soja) for the control of the pest in growers' fields. Concurrently, a technique was developed to allow an adequate formulation of the virus. Presently, nearly 1 million ha of soybean are sprayed annually with the virus (Moscardi and Sosa-Gómez, 1992). Since the beginning of the programme in 1983, about 5 million ha have been treated with this pathogen, with savings of about US$ 50 million (Guia Rural EMBRAPA, 1991).

The success of this programme is manifest in the savings it represents to growers, most of whom are high-income farmers. In addition, there has been a dramatic improvement in human skills at all levels, due to the more than 500 courses on IPM technology, insect recognition and importance of natural enemies provided during the implementation of the programme. Information on IPM technologies delivered by the extension service through a weekly TV programme was a significant factor in the high performance of the IPM programme.

The recent use of *Trissolcus basalis*, a wasp that parasites eggs of stink bugs, delineates a new scenario for control of these insects. This is a relatively new development in the soybean IPM programme, and has already resulted in further reduction in insecticide use in this crop.

Colombia

Research conducted by the ICA has demonstrated that the important soybean pests in Colombia (*A. gemmatalis*, *Omiodes indicata* and *Semiothisa abydata*) are significantly attacked by naturally occurring *Trichogramma* species. This natural control, supplemented by occasional timely releases of laboratory-produced *Trichogramma*, can effectively maintain these pests below the economic damage level. Adoption of this practice in Colombia has markedly reduced the use of pesticides in soybean. The cost of control of these insects now represents only 10–20% of former levels when there was a total reliance on chemical control (Garcia, 1990).

Paraguay

Efforts to implement a soybean IPM programme were initiated in this country in 1982. Today, this programme represents one of the most spectacular examples of technology adoption, conveyed by international technical cooperation between Paraguay and Brazil. The central point of the programme refers to the biological control of the velvetbean caterpillar, *A. gemmatalis*, the most important pest of soybean in Paraguay, by application of *Baculovirus anticarsia* (Servian de Cardozo, 1990).

The cooperative 'Colonia Unidas' adopted the programme in 1985. In 1988/89, the cooperative deployed the programme in almost 19 000 ha, reducing by more than 50% the number of insecticide applications without any significant yield loss (Servian de Cardozo, 1990). In that season, the cost of *Baculovirus* treatment was only 12.5% of that of insecticide treatments, resulting in savings of US$ 416 000. Although more recent information is not available, the goal of the cooperative was to use the IPM programme in 35 000 ha in 1989/90, which corresponds to half the total area planted to soybean by the cooperative.

Sugarcane

Brazil

The sugarcane borer, *Diatraea saccharalis*, is the most harmful pest, being responsible in Brazil for annual losses of more than US$ 100 million (Macedo and Botelho, 1986). Even so, no chemical control is used against this pest. Instead, a successful biological control programme based on releases of parasitoids was developed and is now used extensively. The most efficient parasitoid is the wasp *Cotesia flavipes* which since 1975 has been mass-produced and released in the field. Currently, more than 30 laboratories have been producing the parasitoid in southern Brazil. The results of this programme show that from 1975 to 1990 the infestation intensity (percentage of attacked internodes) was reduced from 6.6 to 3.7% (Macedo *et al.*, 1992).

The sugarcane planthopper, *Mahanarva posticata*, is another serious pest in northeastern Brazil, significantly reducing the yield if not controlled. The fungus *Metarhizium anisopliae* has been used successfully for the control of this pest for almost 20 years. Since 1975 many sugar mills in the state of Pernambuco have constructed their own laboratories to produce *Metarhizium* for planthopper control. From 1970 to 1991, approximately 38 000 kg of *Metarhizium conidia* were produced by IAA/PLANALSUCAR (Sugar and Alcohol Institute), IPA (State of Pernambuco Agricultural Research Enterprise) and other private laboratories (Marques, 1992). This amount was sufficient to spray the pathogen over 474 000 ha of land infested with planthoppers. From 1977 to 1987 this programme led to a 72% reduction in infestation, and contributed to drastically decreased insecticide use. From 1985 to 1987, only 12 000 ha were treated annually with insecticide which corresponds to less than 10% of the area treated in 1971.

Recent information shows that the programme covers an area of 150 000 ha and has substantially decreased the damage caused by planthoppers.

Colombia

Chemical control in sugarcane in Valle del Cauca was totally replaced by an IPM programme which is based on periodic releases of parasitoids for the control of the key pest *Diatraea saccharalis*. The egg parasitoid wasp *Trichogramma pretiosum* and the larval parasitoid flies *Paratheresia claripalpis*, *Metagonistylum minense* and *C. flavipes* are produced by the sugar mills for use in their own plantations.

With the adoption of this control programme, the intensity of infestation of *Diatraea* dropped from 10.6% to 2.9% between 1972 and 1985, despite the increased cultivation with susceptible varieties (Escobar, 1986). Since 1976 the infestation intensity has not exceeded the economic damage level. This case represents one of the most outstanding examples of efficient biological control in the country.

Peru

The first case of laboratory multiplication of natural enemies in Peru for field release against insect pests was initiated by the Sugarcane Growers Committee. *Trichogramma minutum* was then produced in large numbers for sugarcane borer control, with excellent results. This had a considerable influence in several countries in South America where *Trichogramma* is extensively used for the control of different pests (Beingolea, 1989).

Since 1960, CICIU (Center for Introduction and Production of Beneficial Insects) has promoted the installation of laboratory facilities in Peru to multiply natural enemies to be used in the control of pests of sugarcane and of several other crops, resulting in considerable benefits to local growers (Beingolea, 1990).

Venezuela

The sugarcane borers, *Diatraea* spp., and the cercopid *Aeneolamia varia* are important pests of sugarcane in Venezuela that have been successfully controlled through an IPM programme which has been used for over eight years.

The former species have been biologically controlled with the introduced parasitoids *Metagonistylum minense* and *Cotesia flavipes*. Clausen (1978) reported a 50% damage reduction after the introduction of *M. minense*, and before the introduction of *C. flavipes*. *Aeneolamia varia* has been controlled by periodical applications of the fungus *Metarhizium anisopliae* and a combination of different cultural methods (weed control, post-harvest burning of crop residues, etc.), although occasional pesticide applications are still necessary. Although only recently intensified, this IPM programme is already used in about 50 000 ha of sugarcane in Venezuela, with good prospects for the near future.

Tomato

Brazil

After its introduction in northeastern Brazil in 1981, the leafminer/fruit borer *Scrobipalpuloides absoluta* became the major tomato pest in that region. Until a few years ago, insecticide applications were unsuccessfully conducted every three days to control infestation.

In 1989, the planted area was expected to be 15 000 ha, but severe infestations with *S. absoluta* reduced that area to 12 000 ha, and losses in the planted areas amounted to more than 50% in most cases (Haji, 1992). Since then, the planted area has been reduced to 5000 ha because of anticipated losses caused by the pest and high control costs. Since the introduction of the pest, the damage caused by this insect has amounted to 140 000 tonnes of tomatoes, equivalent to economic losses of about US$ 8 million (Haji, 1992). Other lepidopteran and mite pests also affect this crop, but their damage is minor compared to that caused by *S. absoluta*.

The IPM strategy adopted since 1990 consists of periodical releases of the parasitoid wasp *Trichogramma pretiosum*, use of *Bt*, establishment of a restricted planting period, post-harvest plant destruction, and clean-up of containers and transporting vehicles. Periodical releases of the wasp have been acknowledged as the most outstanding technique in this IPM programme, and as a result three large laboratories have been constructed in the region for the production of this species, which until recently had been imported from a commercial laboratory in Colombia.

Colombia

As in northeastern Brazil, the major tomato pest in Valle del Cauca is *S. absoluta*. Periodical releases of *T. pretiosum* and sprays of *Bt*, combined with the natural efficiency of the native *Apanteles exiguum*, are efficient enough to maintain this pest under control.

The use of the IPM programme has practically eliminated the need for the 40 annual insecticide sprays done previously, and reduced the cost of control by about 70%. In 1988, it was concluded that 70% of tomato growers had completely abandoned insecticide use in their pest control strategies (Garcia, pers. comm.). In the Department of Valley del Cauca, *Trichogramma* has been successfully used for the control of several lepidopteran pests on a number of other crops such as soybean, common bean, cassava, maize and sorghum.

Wheat

Brazil

Brazil was ranked among the largest world importers of wheat for many years. As a result of incentives and subsidy policies adopted by the federal government and with the development of newly improved varieties, the cultivated area expanded towards lower latitudes. To reduce the severity of damage caused by introduced aphid pest species, an IPM programme was initiated in 1978 by EMBRAPA/CNPT (Brazilian Agricultural Research Corporation/National Wheat Research Center), based mostly on the introduction of effective parasitoids and predators from overseas.

About 3.8 million parasitoids were released throughout the wheat-growing areas of the states of Rio Grande do Sul, Paraná and Santa Catarina (Gassen and Tambasco, 1983). Until 1977, practically all growers used insecticides for pest control. In 1982 after the programme was initiated, only 6% of the growers were still using insecticides.

This programme prevented the use of 1 million litres of insecticide in the state of Rio Grande do Sul in 1977 and of 1.6 million litres in the state of Paraná in 1989, representing savings of more than US$ 15 million (Gassen and Tambasco, 1983; Guia Rural EMBRAPA, 1991). The cumulative benefits added year after year have promoted significant savings to growers and to the country.

Chile

In 1972, two aphid species, *Sitobium avenae* and *Metopolophium dirhodum*, were detected on wheat. Because of their rapid outbreak, aerial applications of insecticides were required for over 120 000 ha. In 1976, the Chilean National Institute for Agricultural Research (INIA), in conjunction with FAO, initiated an IPM programme for this crop (Altieri *et al.*, 1989). As part of the strategy, several aphidophagous natural enemies were introduced against *M. dirhodum* and *S. avenae*. Five species of predators were introduced from South Africa, Canada and Israel; nine species of parasitoids were brought from Europe, California, Israel and Iran (Zúñiga, 1986). In 1975 more than 300 000 coccinelids were mass-reared and released, whereas from 1976 to 1981 more than 4 million parasitoids were distributed throughout wheat fields in the country. Aphid populations are now kept below the economic damage level by the introduced biological control agents (Zúñiga, 1986).

Table 3.2 shows estimated costs of chemical control for some pests had biological control not been introduced. The biological control programme in Chile represents an annual saving of US$ 20 million in relation to insecticide use alone. To these benefits, environmental conservation should also be added (Zúñiga, 1985).

Table 3.2. Estimated costs of chemical control of seven important South American pests in the absence of imported natural enemies that keep them under complete or substantial control[3]

Pest	Area of host plants(ha)	Sprays per year	US$/spray (per ha)	US$
Icerya purchasi	12 928[1]	2[a]	44.67	1 155 179
Saissetia oleae	40 783[1]	1[a]	44.67	1 822 079
Eriosoma lanigerum	18 766[1]	2[b]	12.60	472 177
Pseudococcus and *Planococcus*				
Citrus	12 492[1]	2[c]	33.87	463 423
Other fruits	6 841[1]	2[c]	33.87	846 232
Aleurothrixus floccosus	12 492[1]	3[c]	33.87	1 269 348
Sitobium avenae and *Metopolophium dirhodum*	463 594[2]	2[b]	12.60	11 664 623
TOTAL	567 896			17 693 061

Sources: [1]ODEPA, 1980; [2]COVARRUBIAS, 1983 (av. of 1975–83); [3]Zúñiga, 1985.
[a]Calculated for Dimethoate (1.0 l/ha) mineral oil (22.5 l/ha)
[b]Calculated for Dimethoate (1.5 l/ha)
[c]Calculated for Metasystox (2.5 l/ha)

Ornamentals

Colombia

A successful case of IPM was developed by a private company, Flores del Cauca SA, located 120 km from Cali. This company maintains almost 20 ha of greenhouses for the production of chrysanthemums. Common pests of this ornamental are leafminers (*Liriomyza trifolii*), aphids (*Myzus persicae*), mites (*Tetranychus urticae*), caterpillars (*Helicoverpa virescens* and *Pseudoplusia* sp.) and the fungus *Bothritis* sp. The IPM programme developed in this case was based on the biological control of the key pest *L. trifolii* with periodical releases of the parasitoid wasp *Diglyphus begini*, hand collection of leaves with leafminer larvae, and collection of leafminer adults with nets and adhesive traps.

Until 1985, 35 insecticide treatments were done during three months for control of *L. trifolii*. Today, chrysanthemums are grown throughout the year, without any insecticide being used for leafminer control. With the adoption of this programme, the cost of pest control was reduced by 72.7% (Escobar, 1986).

Livestock

Brazil

The horn fly, *Hematobia irritans irritans*, the tick, *Boophilus microplus*, and the torsalo, *Dermatobia hominis*, are the main ectoparasites of intensively raised cattle. Since the spread of the horn fly all over Brazil during the last decade, a major effort has been dedicated to the development of an integrated management programme for these arthropods. The management programme consists basically of an integration of chemical, physical and biological control measures (Honer *et al.*, 1990; Honer and Gomes, 1992). The biological control method used refers to the recent introduction of the beetle *Onthophagus gazella*, which promotes the faster recycling of the faeces, inhibiting development of the flies. At the moment, there is no evaluation of the economic impact resulting from the implementation of this programme.

NEW ONGOING IPM PROJECTS

In addition to the IPM programmes already implemented, there are a number of other projects which are in various stages of development. One such project makes use of a virus, *Baculovirus spodoptera*, to control the most important maize pest, *Spodoptera frugiperda* (Valicente *et al.*, 1988; Valicente and Cruz, 1992). Promising results have been obtained in trials conducted in extensive maize plantations in Brazil (Valicente and Cruz, 1991).

Another such project is on sustainable cassava plant protection. Funded by UNDP, it is being conducted in northeastern Brazil and four African countries: Benin, Cameroon, Ghana and Nigeria. Control measures are based heavily on biological and cultural methods; planting systems which are known to result in reduced pest problems are being enforced.

Cooperative pest control programmes involving the use of pathogens are being sponsored by PROCISUR/IICA (Cooperative Programme for Agricultural Research in the Southern Cone) to be conducted in southern South America for the control of several lepidopteran pests. The development of these programmes has been considered a priority in PROCISUR's newly revised lines of activity.

CONSTRAINTS TO IPM USE IN SOUTH AMERICA

Despite the commonly known advantages of using IPM strategies, often the implementation of such a programme can be a relatively long process. Most of the reasons for this are probably not peculiar to South America, but instead reflect the characteristic complexity of agriculture in terms of its response to a given modification applied to slightly different ecologies. This special characteristic demands that exhaustive studies be conducted prior to the extension and implementation of a new IPM programme.

There are six kinds of major constraints to the adoption of IPM programmes, as follows:

- *Technical*—Lack of basic technical studies on pests and their natural enemies; effective and economic means of production of natural enemies; quality control of commercially produced natural enemies; possible positive or negative interactions between different means of pest control; adequate determination of economic injury levels.
- *Institutional*—Scouting services not organised as is frequently found in developed countries; difficulty in transferring knowledge to growers; weak linkages between research and extension services and private field consultants.
- *Economic*—Competing simplicity and apparent efficacy of chemical control; high cost of selective pesticides; cosmetic damage resulting in lower prices for IPM-produced goods.
- *Social*—Inadequate production structure; tendency for utilising traditional (i.e. chemical) control methods.
- *Legislative*—Inadequate laws referring to production, registration and use of commercially produced natural enemies; non-effective enforcement of legislative control measures.
- *Educational*—Illiteracy; low level of basic knowledge of IPM by the growers; reluctancy in adopting economic injury levels.

IPM developers are normally interested in putting to use bits and pieces of important information often obtained from different specialists which first have to be made compatible. Once this is done, the IPM developer has to be qualified to make the programme attractive to potentially interested growers. Thus, the possible bottlenecks in the widespread adoption of an IPM programme are the development of the programme itself and the ability of the specialist in convincing the growers about the advantages of the system.

The first difficulty in the above process arises from the fact that in most countries there is no adequate training curriculum for workers in IPM, one that adequately covers the full range of knowledge required. Secondly, the kind of multi-disciplinary working pattern required in the development and implementation of an IPM programme is not customarily practised among South American workers. Thirdly, the prevalence of illiteracy in the rural areas of South America makes it difficult for growers to assimilate and store all the information necessary during different periods of the growing season. Although this is often not important after growers have adapted to the IPM programme, it is of the utmost importance in the learning phase. The fourth type of difficulty refers to the so-called 'socialisation of production costs', i.e. the deferment of immediate payment for the overuse or misuse of natural resources by growers. This leads to a temporarily high income for 'business' growers and to pressure for above-optimum use of inputs; this is especially true in countries with considerable potential for agricultural expansion. In such situations, inputs are equated to 'means of assurance', making 'more complex' growing systems less attractive.

A LOOK TO THE FUTURE

The importance of South America as a world producer of agricultural goods is already considerable and is likely to increase. External influences, especially those related to international market prices, are changing the relative importance of crops to different regions of South America. Internally, the change in the relative importance of different crops is mainly due to the formation of commercial regional groups. It is expected that crops like wheat and sugarcane will be most affected, because of the marked differences in suitability of the ecosystems where these crops are grown. Very often, even the most modern technology cannot adequately overcome less-than-optimal natural environmental conditions.

Thus, when competition prevails, a substantial rearrangement of agricultural activities will most probably occur. It is expected that the rearrangement should favour agricultural sustainability, primarily by fostering the cultivation of crops in their respective ecologically optimal areas. This will certainly affect the degree of pest problems in the subcontinent.

The concept of systems management (Delucchi, 1989) will be progressively incorporated into the cropping systems used, so as to reduce the need for any sort of pest control. To this end, the real causes of pest upsurges will be evaluated, in an effort to select the most appropriate crops to be grown under a specific set of ecological conditions and under ecologically optimised cultivation patterns in which organisms are less harmful to crops. Appropriate planting periods, patterns of crop rotation, quantities and kinds of fertilisers and other inputs, weeding, etc., will be studied in an attempt to reduce the need for pest control.

As a follow-up to the recently intensified public outcry against environmental degradation, it is expected that considerably more attention will be given to the economic assessment of total costs of agricultural production systems. This should lead to the development of criteria for environmental impact assessments for crops grown in each ecosystem. Institutional programmes dedicated to such studies have already been prepared by national research organisations, particularly by the Brazilian Agricultural Research Corporation (EMBRAPA) and the Argentinean National Institute for Agricultural Technology (INTA). International regional organisations, such as centres of the CGIAR system and the IICA, have also recently adopted a much more active position in relation to the maintenance of the natural yield capacity of ecosystems at risk. In this respect, priority programmes which focus on conservation of natural resources and agricultural sustainability have been established. It is envisioned that new patterns of sustainable agriculture will be designed to reduce the dependence on chemical and other energy-based inputs, to minimise the ecological risks resulting from farming practices, and to enhance agricultural productivity in relation to available resources (Mackauer, 1989).

IPM in South America will lead to a gradual withdrawal in pesticide use. Those chemicals most aggressive to the environment and most toxic to humans will be banned through restrictive environmental laws in response to the pressure from society. They will be replaced by chemicals that are safer and less persistent in the environment.

Multinational private corporations will continue to adjust their businesses to cope with international trends related to pest control. Chemical producers will continue to support the development of IPM programmes, by sponsoring training courses and changing the quality of the products they commercialise along the lines of increased specificity and decreased negative environmental impact (Campanhola *et al.*, unpublished).

Meanwhile, alternative methods of pest control will become increasingly important, as development of resistant plant varieties, biological control and cultural practices are intensified. Biotechnology will play an important role in the development of resistant plant varieties in several regional research institutions which have been supporting the establishment of necessary infrastructure and the appropriate training of personnel. Formal regional efforts in this area have been adopted by national research institutions, by CGIAR research centres operating in South America, and through the cooperation programmes of the IICA.

Operation of warning stations for different crops based on meteorological parameters and implementation of routine scouting services will lead to early detection of pest outbreaks and rational use of chemicals or other methods of control.

Considering the successful use of certain groups of organisms for the control of important pest species, more consistent development of biological control strategies is expected. For example, the use of predators for the control of phytophagous mites should receive attention in the near future (Moraes, 1992). Use of *Trichogramma* spp. for the control of several lepidopteran pests should also be more extensive (Garcia, 1990). This will be facilitated by the interest of large private organisations which are the users of those organisms, or which seek to commercially produce them.

Adequate production schemes for efficient natural enemies, development of new entomopathogen formulations and technically appropriate release methods for augmented natural enemies will favour widespread adoption of biocontrol practices. More effective delivery of pesticides and natural enemies to target sites will reduce production costs and deleterious effects to the environment.

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Executive Summary and Recommendations

The reviews presented in this book have served to spotlight the efforts being made on three continents—Africa, South/Southeast Asia and South America—to develop and implement IPM programmes adapted to specific regional pests and ecologies. The reviews attempt to analyse the difficulties and shortcomings of past IPM programmes, but also to record the benefits achieved thus far in terms of both monetary value and environmental impact.

In this section, the editors have attempted to summarise the suggestions offered by the authors for circumventing past limitations, in the hope of improving the efficacy of future IPM projects. The constraints to IPM in each region have been described around five broad areas: technical (including R&D); institutional; policy; social and educational.

It is apparent from the three reviews that a region's pest problems cannot be solved by a single prescription, nor a clear-cut recipe. The entire agro-ecosystem must be considered as an organic whole when designing a control strategy. A crop and its pests must be viewed in the context of its environment—the soil, water, season, surrounding vegetation, etc. An IPM strategy therefore becomes a series of decision-making steps in which each component must be carefully weighed and assessed at each step of the way.

The reviews also illustrate the dynamic nature of IPM. IPM is a management system that must continually evolve because the pests themselves and their environment are continually evolving and changing.

The chapters also serve to underline the need for evolution of IPM from a primarily pesticide-centred approach to a more sophisticated biologically intensive management system, where pest numbers are reduced through such tactics as habitat management, manipulation of insect basic biology and behaviour, alteration of the insect–plant (or animal) host relationship, and so on.

Integrated pest management (IPM), as so succinctly described in

Integrated Pest Management in the Tropics: Current Status and Future Prospects
Edited by Annalee N Mengech, Kailash N. Saxena and Hiremagalur N. B. Gopalan

these reviews, is therefore not a simplistic solution to a complex pest problem. It must involve a cohort of environmentally sensitive and knowledgeable actors—from the farmer end-users, through the extensionists, researchers, and policy-makers—working together to produce a sustainable solution that can, as has been illustrated, bring about yield gains equivalent to pesticide use, but at a much lower social and environmental cost. This is the challenge for the remainder of the 20th century.

GENERAL OBSERVATIONS ON THE STATUS OF IPM IN THE TROPICS

1. IPM can be viewed as an ecologically sound, viable alternative to pesticide use. It can also be seen as the most appropriate and acceptable pest control strategy for the great majority of small farmers in the tropics.
2. The high crop diversity, traditional practices of intercropping and intensively managed smallholdings are factors which favour implementation of IPM on small-scale farms in the tropics. Many IPM technologies involve only a single low-cost input and are therefore more affordable than expensive chemical control.
3. At the same time, plantation crops are particularly suited for IPM, because of the simple agro-ecosystem prevailing over a large area and the equilibrium possible between biotic and abiotic factors. Large-scale farmers often have the money to risk in new ventures, and are often the first to adopt IPM in an area.
4. The prevailing trend in tropical countries still tends to favour increased use of chemical pesticides, however. There is a common misconception, often encouraged by chemical companies, some governments and even donors, that pesticides are essential for high yield. This appears to be verified by the increase of pesticide consumption in tropical countries. Within the last decade it is estimated that pesticide usage grew by 200% in Africa, 40% in Latin America, and less than 25% in Asia. The average growth in the developing countries was about 55% as against 20% for the world total.
5. Wide-scale adoption of IPM faces two major bottlenecks, one being the difficulties in developing an appropriate IPM programme in which the components are all compatible, and the other being the

difficulty the IPM specialist faces in convincing growers about the advantages of the system.

6. Major constraints to the adoption of IPM programmes fall into six categories:

   - *Technical*—Lack of basic technical studies on pests and their natural enemies; effective and economic means of production of natural enemies; quality control of commercially produced natural enemies; possible positive or negative interactions between different means of pest control; adequate determination of economic injury levels.
   - *Institutional*—Scouting services not organised as is frequently found in developed countries; difficulty in transferring knowledge to growers; poor linkages between research and extension services and consultants.
   - *Economic*—Competing simplicity and apparent efficacy of chemical control; high cost of selective pesticides; cosmetic damage resulting in lower prices for IPM-produced goods.
   - *Social*—Inadequate production structure; tendency for utilising traditional (i.e. chemical) control methods.
   - *Legislative*—Inadequate laws referring to production, registration and use of commercially produced natural enemies; non-effective fiscalisation of legislative control measures.
   - *Educational*—Illiteracy; low level of basic knowledge on IPM by the growers; reluctancy in adopting economic injury levels.

OBSERVATIONS ON THE STATUS OF IPM IN AFRICA

1. The majority of African farmers are smallholders, who frequently do not own the land they cultivate. African farmers have practised one form of IPM for centuries, by their traditional methods of intercropping, terracing, seed selection, and planting of cultivars maturing at different times.
2. In spite of this traditional foundation, pesticide use is growing in Africa at the highest rate in the world. There is very little hard data available on the consumption and use of chemicals in Africa, however, and on their breakdown into herbicides, fungicides and insecticides.
3. The enormous increase in largely uncontrolled use of pesticides could mean that Africa is at the brink of a chemical-induced dis-

aster. Less than half of all African countries appear to have legislation on pesticides and most countries cannot comply with all the provisions of the FAO Code of Conduct on the import/export, distribution and the use of pesticides. Sudan is the only African country that has adopted IPM as its official policy of crop protection.

4. Work on single IPM components (e.g. resistant varieties, biological control, etc.) is common on the African continent, although there are few comprehensive IPM projects. This may be due to the fact that governments and donors pay scant attention to alternative plant protection measures when planning and implementing agricultural and rural development projects.
5. The importance of research in development in general and in IPM adoption, in particular, is not appreciated by most African governments and donors, the latter being the major funders of IPM projects. In fact, many donor countries continue to donate harmful broad-spectrum pesticides.
6. Very few applied research results on IPM are available. Many applicable results have yet to be transmitted in an effective and comprehensive form to planners and farmers. Governments will be more attracted to support research and extension when more results are available.
7. There are too few personnel available for crop protection activities, and most are not adequately trained for their jobs. Lack of access to the literature, lack of transport and the necessary equipment, and low salaries all tend to inhibit implementers of IPM.
8. Extension services in Africa are grossly underdeveloped and underfunded, resulting in poor training of farmers. There are too few women extension agents, thus posing communication problems with the majority of (women) farmers.
9. On-farm constraints to the adoption of IPM in Africa include shortage of labour for time-consuming activities such as weeding; neglect to include the (majority) women farmers in IPM programmes; lack of capital to purchase the more expensive selective insecticides.
10. Policy constraints include the general lack of investment by African governments in smallholder agriculture, thereby preventing the conversion of subsistence farmers into cash-earners. Government subsidies for pesticides may hamper IPM implementation by making it difficult to convince farmers of the advantages of IPM;

likewise, incentives in the form of free fertilisers and extension inputs may cause farmers to lose initiative.

11. Inadequate training in the use of economic injury levels leads to overuse of pesticides, particularly among smallholders. Such is the case among coffee growers in Kenya, for instance.
12. IPM needs to be developed for the following: vegetables, citrus, agroforestry, weeds (including unwanted trees), and stored products.

OBSERVATIONS ON THE STATUS OF IPM IN ASIA

1. Crop protection in Asia continues to be dominated by an increasing dependence on chemical pesticides for agricultural, public health, and home use. Practices such as calendar spraying and aerial spraying are widespread.
2. The Asian share of the world pesticide market was estimated at about 27% in 1990, of which 46% comprised insecticides. Important among these are DDT, BHC, methyl parathion, malathion, and endosulphan. Rice consumes over 40% and fruits and vegetables about 33% of the total volume.
3. The striking reduction in pesticide consumption (50% in a two-year period from 1986 to 1988) in Indonesia can be attributed to the success of their national IPM programme and the removal of government pesticide subsidies.
4. Ten countries in Asia have pesticide legislation regulating the production, import, export, handling and use of pesticides, and it is likely that most countries in the region will have regulations in place within the 1990s. However, enforcement of these regulations is generally weak.
5. IPM has been adopted as the official policy of crop protection in most Asian countries. Government surveillance and forecasting programmes exist in eight countries: China, India, Indonesia, Malaysia, Korea, Pakistan, the Philippines and Thailand. IPM exists in one form or another in most countries.
6. In spite of the above, the large-scale adoption of IPM by farmers remains limited even though IPM has been demonstrated to be an economically viable alternative to pesticide use in numerous projects over the past two decades.
7. The prevailing agricultural policy framework is a major factor hin-

dering the implementation of IPM in the region. Examples of such policy elements are pesticide subsidies; lack of government regulations for IPM methods; credit packages which include pesticide purchases and regular application as one of the technologies; crop insurance programmes which encourage prophylactic applications of pesticides and compensation for pest damage *only* if fields are treated, and so on.

8. A negative 'information environment' tends to encourage continued increases in pesticide use by subtle implications that high rates of chemical consumption are an indicator of progress. Agrochemical companies tend to reinforce the impression that pesticide use is an official government policy and that it is under strict control and poses no risk.
9. The development of resistance to pesticides, particularly in major vegetable pests and cotton, is a serious problem in Asia, and constitutes an important underlying cause of pesticide dependency in farmers, driving them to search for stronger pesticides.
10. IPM approaches have succeeded in reducing the use of broad-spectrum pesticides and a number of studies have shown IPM to be more economical than conventional methods based on the use of chemicals. However, adoption of the practice of IPM at the farm level still encounters several difficulties such as adoption of recommended threshold levels.
11. The focus has shifted from pest control to pest management, from varietal resistance to tolerance, and from yield advantage to yield stability.
12. A striking change from the past is the emphasis now being placed on the use of biological control agents in developing IPM strategies. Various novel approaches, including the possible use of transgenic plants, are becoming fashionable. The private sector has an important role to play in developing and marketing biological control agents.
13. Nevertheless, it appears as if pest control in the next decade in tropical Asia will continue to depend overwhelmingly on making the best use of conventional methods, including conventional pesticides, as part of IPM.

OBSERVATIONS ON THE STATUS OF IPM IN SOUTH AMERICA

1. Agriculture remains the main economic activity in South America, and the potential for expanding its share of world agricultural markets is high. There is a growing environmental consciousness among the population, promoted by the recent United Nations-sponsored Conference on Environment and Development (UNCED) Rio de Janeiro, 1992.
2. In the diverse agricultural climate of the sub-continent, IPM is seen as playing a major role in allowing the full production potential of each crop to be maximised while conserving the natural yield capacity of the underlying ecosystem.
3. Environmental pollution from agricultural activities is recognised as being especially serious in Chile, Argentina and southern Brazil and particularly in soybean-growing areas of southern South America, but very little hard data exists about the effects of degradation/pollution on biological processes.
4. Latin American pesticide consumption corresponds to about 10% of the global pesticide market. Nearly 50% of this is due to Brazil which is sometimes considered as the largest potential market for pesticides. Half of the insecticides used in Brazil are on three crops: sorghum, fruit trees and cotton.
5. Recent successful IPM programmes have considerably reduced the demand for pesticide applications on cotton and fruit trees in several countries, and reduced overall consumption by 40% in Brazil.
6. It is anticipated that the implementation of regional commercial groups such as MERCOSUL and the Andean Pact will help bring about harmonisation of regulations and registration of pesticides within the region and the increased demand for lower levels of pesticide residues in food.
7. The media has played an important role in promoting environmental conservation in South America, but more programmes are required to target the rural (largely illiterate) population.
8. The private sector is playing a progressively important role in implementing IPM programmes by making available essential IPM components, particularly for biological control. Parasitoid production is being done by private laboratories in Colombia (20 laboratories), Peru (23), Venezuela (12) and Brazil (30). Most sugar mills maintain a permanent production of parasitoids to combat

the sugarcane borer. The natural enemy business appears to be a thriving enterprise in South America.

9. IPM development is also taking place in agricultural colleges and local and international research institutions as well as by NGOs, who help provide low-input technologies.
10. IPM programmes for soybean have reduced the numbers of insecticide applications by 50% in Argentina by use of natural enemies and resulted in savings of US$ 200 million annually in Brazil; the latter savings were achieved partly due to the use of a pest-specific *Baculovirus*.

RECOMMENDATIONS

1. Initiatives for the development of IPM will need to come from researchers and policy-makers, not from cash-strapped farmers nor from chemical companies with vested interests.
2. Governments must take actions that will make chemical control less attractive, such as through legislation, registration and taxation.
3. Governments must take a proactive role in developing and implementing IPM programmes, by providing financial support and appropriate incentives.
4. Pesticide subsidies must be removed and the resources diverted to funding of IPM research, education and extension services.
5. Farmers' favourable perception of IPM is most important, and emphasis should be placed on developing their resourcefulness and management abilities through intensive field training. For instance, they must be taught to monitor their own crops for determination of threshold levels, and, better still, be taught about ecosystem analysis which fits better with the 'multifactorial world of farmers'.
6. The conservation of natural enemies should be recognised as one of the most important aspects of a sound agricultural management policy. This can be achieved by intercropping, elimination or highly restricted use of broad-spectrum insecticides, etc.
7. More consistent development of biological control strategies is needed, for instance in the use of predators for the control of phytophagus mites. Efficient production and delivery schemes for

natural enemies and entomopathogens need to be developed, as well as appropriate release methods for augmented natural enemies.

8. Intercropping as an IPM component should be encouraged because of its favourable impact on maintaining general biological diversity in the face of the unreliability of varietal resistance.
9. Implementation of multi-crop IPM across the entire agricultural rotational cropping system (especially for rice) should be promoted as a means of reducing pesticide usage in general and preserving the natural enemies that carry over between crops.
10. Pesticide resistance management must be viewed as an integral part of an IPM strategy. There is an urgent need to develop a sound resistance management strategy, particularly for synthetic pyrethroids. (Such a strategy is in the initial stages of implementation for cotton in India.)
11. The concept of 'systems management' needs to be progressively incorporated into the cropping systems used in order to reduce the need for all types of pest control. Crops will need to be more carefully selected for their appropriateness to a specific regional ecology and the optimal cultivation patterns determined.
12. The role of biotechnology in developing resistant plant varieties needs to be expanded by establishing the necessary infrastructure and appropriate training of personnel.
13. The promotion of botanical pesticides such as neem as low-cost technologies must be underpinned with improved formulations, development of on-farm production techniques, and standardisation for biological efficacy.
14. Multinational corporations and chemical producers should be encouraged to support the development of IPM programmes by sponsoring training courses on the safe handling and use of pesticides and ensuring the increased specificity and safer environmental impact of their products.
15. Criteria for evaluating the environmental impact assessment for crops grown in each ecosystem need to be developed.
16. Operation of crop-specific warning stations based on meteorological parameters and implementation of routine scouting services is needed in some countries to assist in early detection of pest outbreaks.
17. More IPM research is needed before applicable recommendations can be provided to farmers, extensionists and policy-makers. For

instance, there is insufficient IPM research on two important subsistence crops, millet and sorghum.

18. The recommended threshold levels for both crop pests and diseases need to be revised, and training materials prepared for all categories of farmers, but in particular for smallholders.
19. More attention should be paid to weeding as an IPM component. Extensionists need training in weed control techniques.
20. IPM needs to be developed for stored products, especially with respect to the larger grain borer which is becoming an increasingly important threat worldwide.
21. Assessment of all IPM projects needs to be done after their completion, so that feedback from farmers and extension staff can be used to guide researchers and policy-makers.
22. The FAO/UNEP Panel of Experts on Integrated Pest Control should be revived, so as to help convince governments of the importance of officially adopting the IPM approach. Donors should also assist in this task.

Index

Acyrtosiphon pisum 132
Aeneolamia varia 141
aerial spraying 87
Africa 1–62, 155–7
  cassava IPM 30–6
  cocoa IPM 47–9
  components of IPM 13–20
  cotton IPM 39–45
  crop and pest situation 2–3
  farming in 1–6
  future roles for IPM 53–6
  IPM development 6–13, 66–7
  livestock/tsetse fly control programmes 50–3
  millet IPM in the Sahel 25–9
  multiple cropping systems 20–5
  pesticide use 4–6, 155–6
  prospects for IPM 56–62
  rice IPM 36–9
  sorghum IPM 29–30
  traditional pest control 3–4, 28
African cassava mosaic virus 32, 34
African Pest Management and Research Network (PESTNET) 12
African Regional Post-Graduate Programme in Insect Science (ARPPIS) 7
African Trypano-Tolerant Livestock Network 51
Africa-Wide Biological Control Programme (ABCP) 33–4
agrochemical industry, *see* pesticide industry
agroforestry 54–5
Alabama argillacea 133
Aleurocanthus woglumi 17
Aleurothrixus floccosus 144
alfalfa 132
Anastatus 103
Andean Pact 123, 159
Antestiopsis 46–7
Anthonomus grandis 122, 134–6
Anticarsia gemmatalis 137–9
ants 18, 48–9, 55
Apanteles exiguum 142
Apanteles flaviceps 99
aphids
  alfalfa 132
  apple woolly 17
  cotton 40, 42
  wheat 143
Aphis gossypii 40
Argentina 122, 127–9, 132, 137
Argentinean National Institute for Agricultural Technology (INTA) 148
Argyrotaenia sphaleropa 136
armyworms 17, 26, 92–3
Asia, South and South-East 69–111, 157–8
  adoption of IPM 70–1
  cotton IPM 94–8
  current IPM policies 71–2
  fruit and plantation crops 100–1
  Green Revolution 107–9
  insecticide resistance 105–6
  IPM implementation 72–3
  neem in pest control 104–5
  pesticide usage 70, 73–82, 109–10, 157
  rice IPM 82–9
  sugarcane IPM 98–100
  vegetable IPM 90–4
  see also specific countries
Asian Vegetable Research and Development Centre (AVRDC) 93
Aspiridiotus 45
Atherigona soccata 23, 30
Aulacaspis tegalensis 17

Azadiracta indica (neem) 94, 104–5
Azolla 38

Bacillus thuringiensis (*Bt*)
  in Africa 20, 43
  in Asia 91, 93, 103–4
  in South America 132, 142
Bactrocera cucurbitae 91
Baculovirus 43, 45
Baculovirus anticarsia 131, 138–9
Baculovirus spodoptera 145
banana 17, 49–50
Bangladesh 74, 80, 85–6
bean fly 91
beans 50
  see also soybean
Beauveria bassiana 103–4, 131
beetles
  blister 26, 28, 54–5
  hispid 39
  ladybird 103
  rhinoceros 101
  rice hispa 83
Bemisia tabaci (whitefly) 32, 40, 41–2, 44, 95
BHC 75, 77, 91
biological control 160–1
  in Africa 16–18
  in Asia 102–4, 110, 158
  in cassava 33–4
  cattle pests 52–3, 145
  classical (CBC) 16–18
  in coffee 46
  in cotton 18, 43, 95, 98, 135
  in millet 29
  in South America 130–1, 143, 144, 149, 159–60
  in soybean 138
  in sugarcane 17, 98–100, 139–40, 141
  in tomato 142
  in vegetables 93
  in wheat 143
biological diversity 85
birds, graniverous 26
blackfly, citrus 17
black pod disease 48
blight, bacterial
  cassava 32, 34
  coffee 46
  cotton 40
  rice 83
Bolivia 125–6, 129
boll weevil 122, 134, 135–6
bollworms, cotton 40, 95, 98, 106, 135
Boophilus microplus 145
borer
  pink 17
  sugarcane 139–40, 141
botanical pesticides 94, 104–5, 161
Bothritis 144
BPH, *see* brown planthopper
Bracon 29, 131, 136
Brazil 122–3, 130, 131
  IPM programmes 132–4, 137–8, 139–40, 141–3
  pesticide use 126–7, 129, 159
Brevipalpus phoenicis 133
Brown hebetor 29
brown planthopper (BPH) 83–4, 87–8, 106
  resistant rice varieties 84–5
Burkina Faso 36–8
Burma 74
Busseola fusca 23, 30

cash-crop farming 4, 105, 122
cassava 30–6, 145
  classical biological control 33–4
  cultivation 31
  cultural control 35–6
  major pests 31–2
  resistant varieties 34–5
cattle 123, 145
  trypanosomiasis 50–3
  trypano-tolerant races 51
Centro de Manejo Integrado de Prags, University of the State of Saõ Paulo (CEMIP) 130
Centro Internacional de'Agricultura Tropical (CIAT) 50

Centro Nacional de Pesquisa de Soja (CNPSo) 131, 138
chemical control
in Africa 19–20
in Asia 109–10
in citrus 132, 133
in coffee 47
costs in South America 143, 144
in cotton 41–3, 95–6, 97–8, 135–6
in millet 28
in rice 37–8, 75–6, 83–4, 85, 87–9
in sorghum 30
in soybean 137–8, 139
in vegetables 91–3
in wheat 143
see also pesticides
Chile 122, 143
Chilo 18, 26, 36–7, 83
Chilo diffusilineus 30
Chilo partellus 23
Chilo sacchariphagus 17
China 71, 80, 103–4
cotton 97
pesticide usage/production 76–7
vegetables 90–1
chrysanthemums 144
Chrysopa sinica 103
Chrysoperla (*Charysopa*) 95, 102
citrus 53, 123, 132–3
Coccus alpinus 45
cocoa 47–9, 100
coconut 18, 100–1
coffee 45–7, 122
coffee berry disease 45–6
Colletotrichum coffeanum 45–6
Colombia
IPM programmes 135, 139–40, 142, 144
natural enemy production 130
pesticide use 128–9
Le Comite permanent Interetats de Lutte contre la Scheresse dans le Sahel (CILSS)/FAO project in the Sahel 20, 21–3, 25
Coniesta (Acigona) ignefusalis 26, 28
Consultative Group on International Agricultural Research (CGIAR) 148–9
Contarinia sorghicola 30
Cooperative Programme for Agricultural Research in the Southern Cone (PROCISOR) 145
Cosmopolites sordidus 49
Cote D'Ivoire 18
Cotesia flavipes 131, 140–1
Cotesia plutellae 93
cotton
in Africa 2, 18, 39–45
in Asia 75, 94–8
in South America 122, 128–9, 133–6
Crematogaster 48–9
Crocidolomia binotalis 94
crop rotation 14
cultural control measures
in Africa 14–16
cassava 35–6
coffee 46–7
cotton 43–4
millet 27–8
rice 37
sorghum 30

DDT 74–5, 77, 91
Dermatobia hominis 145
Diadegma semiclausum 93
Diadromus collaris 93
diamondback moth (DBM) 91, 92–4, 106
Diatraea 141
Diatraea saccharalis 139–40
Diclasdispa armigera 83
Diglyphus begini 130, 144
donors, international
IPM policies 6–7, 61–2
supply of pesticides 5, 156

Earias 95
Echinochloa 37, 83
Eichhornia crassipes 103

Eldana saccharina 23
Empoasca lybica 40
Empresa Brasileira de Pesquisa Agropecuria (EMBRAPA) 131, 138, 148
Entada africana 54–5
environmental degradation 107–8, 124, 159
environmental conservation 124–5, 159
Ephestia 29
Epicauta villosa 55
Epidinocarsis lopezi 33
Epiricania melanoleuca 99
Eriosoma lanigerum 17, 144
eucalyptus weevil 17
Eulophontus myrmeleon 48
Euphorbia heterophylla 38
Eurystylus 30
Euschistus heros 137
extension services, African 7, 57, 59, 156

fallow 14
FAO, *see* Food and Agriculture Organization of the United Nations
farmers 57–9, 160
  constraints on IPM adoption, in Africa 22–3, 25, 29, 44, 58
  monitoring of pests 73
  neem use 105
  progressive (innovators) 58–9
  traditional pest control practices 3–4, 28
  training of 24, 59, 157
farming
  African 1–6
  South American 122–5
feedback 59–60, 162
fertilisers 23, 43–4
fires, in pest control 28
Food and Agriculture Organization of the United Nations (FAO) 70–1
  Intercountry Programme for Integrated Pest Control in Rice 89
  /UNEP Panel of Experts on Integrated Pest Control 61, 162
fruit
  in Africa 49–50, 53–4
  in Asia 75, 100–1
  in South America 123, 128–9
fungicides
  seed treatment 19
  use in South America 126–8
Fusarium oxysporium 40

gall midge
  rice 83
  sorghum 30
Gambia 54–5
Ghana 47–9
Gonipterus scutellatus 17
government policies
  in Africa 5, 6, 23, 61–2, 156–7
  in Asia 71–2, 102, 110–11, 157–8
  recommendations 160
grain borer, larger 56, 162
grasshoppers 26
Green Revolution 107–9
Gyranusoidea sp. 17–18

headbug, sorghum 30
Helicoverpa 16, 18, 43, 136
Helicoverpa armigera, 40, 91, 95, 98, 102, 106
Heliocheilus (Raghuva) albipuctella (millet spike borer) 26, 28–9
Heliothis, *see Helicoverpa*
Heliothis armigera, *see Helicoverpa armigera*
Heliothis virescens 133, 135, 144
Hellula undalis 94
Hematobia irritans irritans 145
Hemilea vastatrix 46
herbicides
  use in Africa 15–6
  use in South America 126–8

Heteronychus licas 17
Heterosylla cubana 55–6
Hibiscus esculensis 44
high-yielding varieties (HYV) 107
Hispa gestroy 39
horn fly 145
horticultural crops, *see* fruit

Icerya pattersoni 45, 46
Icerya purchasi 144
ICIPE, *see* International Centre for Insect Physiology and Ecology
ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 26–8, 30
India 80, 101–3
  cotton 95–6
  pesticide usage/production 77, 101
  pest surveillance 71, 102
  sugarcane 99
  vegetables 90, 91–2, 94
Indonesia 71, 72, 80, 93, 100–1, 157
  pesticide usage 73–4, 78, 87–9
  rice IPM 87–9
information networks, Africa 12–13
inoculation 18
insecticides
  resistance 90, 105–6
  resistance management (IRM) programmes 106
  use in South America 126–8
  see also pesticides
Institut de Sahel (INSAH) Pest Management Technical Coordinating Unit 12–13
integrated pest management (IPM)
  constraints on adoption 146–7, 155
  definition 1
  recommendations 160–2
  status in tropics 154–5
Integrated Pest Management for Rice Network (IPM-R) 89
integrated vector management (IVM) 50–3
intercropping 3, 4, 161
  in Africa 14–15, 23
  cotton–wheat 97
international agricultural research centres (IARCs) 7, 12, 56–7, 60–1
International Board for Plant Genetic Resources (IBPGR) 14
International Centre for Insect Physiology and Ecology (ICIPE) 13, 30
  IPM project in western Kenya 20, 23–4, 25
  tsetse fly control 52
International Code of Conduct on the Distribution and Use of Pesticides 5
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) 26–8, 30
International Group of National Associations of Agrochemical Industries (GIFAP) 106
International Institute of Agricultural Sciences (IICA) 145, 148, 149
International Institute of Biological Control (IIBC) 16, 17
International Institute of Tropical Agriculture (IITA) 13, 33, 50
International Network for the Improvement of Banana and Plantain (INIBAP) 50
International Rice Research Institute (IRRI) 84–5, 89
inundation 18
IPM, *see* integrated pest management
Isotema javansis 99

jacaranda bug 17
Japan 74, 76
jassid 40

Kenya
  coffee IPM 45–7
  western, ICIPE project 20, 23–4, 25
Korea, Republic of 71, 78, 81

labour shortages 15, 127
land ownership/tenure 2
Lantana camara 55
leafhopper, green rice 87, 106
leafminers 45
leaf rust, coffee 45–6
leaf webber 94
leafworm, cotton 133
legislation, pesticide 61, 78–82, 110
Leucaena 55–6
Leucaena leucoceophala 55
Leucania loreyi 17
Leucinodes orbonalis 91
Leucoptera 45
Liriomyza trifolii 144
livestock
 in Africa 50–3
 in South America 123, 145
locust, red 17

Macromischoides 48
Madagascar 38–9
Mahanarva posticata 140
maize 23, 50, 122, 145
maize streak virus 13, 50
malathion 77
Malaysia 71, 74, 80, 92–3, 100
Maliarpha 36
Maliarpha seperatella 38
mango 17–18
Manihot esculenta, *see* cassava
Maruca testulalis 23
Mauritius 17
mealybugs
 cassava 16–17, 31–2, 33–5
 citrus 47–8
 cocoa 47–8
 coffee 17, 46
 mango 17–18
mechanical control, insect pests 16
melon fly 91
MERCOSUL 123–4, 129, 159
Metagonistylum minense 131, 140–1
Metarhizium anisopliae 131, 140–1
Metopolophium dirhodum 143–4
millet 2
 IPM in the Sahel 22, 25–9
millet spike borer (*Heliocheilus*) 26, 28–9
minah bird 17
mite
 cassava green 31–2, 34–5
 citrus rust 133
 leprosis 133
mixed cropping 3
monitoring systems, pest 19, 73, 103
 rice 37–9
Mononychellus tanajoa (cassava green mite) 31–2, 34–5
multiple cropping systems 20–5, 161
mustard 94
Mysus persicae 144

nagana 50–3
 see also trypanosomiasis
national agricultural research (and extension) systems (NAR(E)S)
 Africa 12–14, 57, 59–61
 South America 129–30
natural enemies
 conservation of 18, 85, 109, 160
 heavy pesticide use and 42
 mass production 130–1, 141
 see also biological control
N'Dama cattle 51
neem 94, 104–5
Nepal 74
Nephotettix cincticeps 106
Nephotettix virescens 87
Nezara viridula 137
Nilaparvata lugens, *see* brown planthopper
Nomadacris septemfasciata 17
Nomuraea rileyi 131
non-governmental organisations (NGOs) 130–1
nuclear polyhedrosis viruses (NPV) 95, 102–4, 138
 see also Baculovirus
Nymphula depunctalis 37

Oecophylla 18, 48–9, 55
Oecophylla longinoda 18
oil palm 100
Omiodes indicata 139
Onthophagus gazella 145
Ophiomyia phaseoli 91
ornamental plants 144
Orseolia oryzae 83
Orthezia insignis 17
Oryctes ceros 101
Oryza sativa, *see* rice

Pakistan 73–4, 78, 81, 97–100
Parachrysocharis javensis 99–100
Paraguay 131, 135–6, 139
Paratheresia claripalpis 140
Pectinophora gossypiella 95
Peizodorus guildinii 137
Pennisetum typhoides, *see* millet
personnel, *see* staff
Peru 128–9, 131, 136, 141
pesticide industry 19–20, 61, 148, 161
  Asian 76–8, 158
  package deal systems 42
  pesticide resistance and 96, 106
pesticides
  acute poisoning 19
  botanical 94, 104–5, 161
  calendar spraying 19
  excessive use 18, 41–2, 90–2, 95–6, 107, 136
  government policies 5, 23, 71–2, 102
  legislation 61, 78–82, 110, 157
  reducing use 85, 88–9, 148
  residues 91
  resistance 90, 105–6, 158, 161
  selective 19–20
  subsidies, *see* subsidies, pesticide
  usage 154
    in Africa 4–6, 155–6
    in Asia 70, 73–82, 109–10, 157
    in South America 125–9, 159
  see also chemical control
PESTNET 12
Pheidole 48
Phenacoccus manihoti (cassava mealybug) 16–17, 31–2, 33–5
pheromones, *Coniesta ignefusalis* 28
Philippines 71, 81, 83, 93
Phyllocoptruta oleivora 133
Phytophthora 48
Planococcus 144
Planococcus citre 47–8
Planococcus kenyae 17, 46
plantain 49–50
plantation crops 75, 100–1
planthopper
  brown, *see* brown planthopper
  sugarcane 140
Platynota 136
Plutella xylostella (diamondback moth; DBM) 91–4, 106
pod borer 23
Pratylenchus 49
private companies
  natural enemy/pathogen production 130–1, 159–60
  see also pesticide industry
Prosopis juliflora 55
Prostephanus truncatus (larger grain borer) 56, 162
Psalydolytta 26
Psalydolytta fusca 54
Pseudococcus 144
Pseudomonas syringae 46
Pseudoplusia 144
Pseudotheraptus 18, 55
Pulvinaria iceyi 17
Pymetrozine 20
Pyricularia oryza 36
Pyrilla perpusella 99

Rastrococcus invadens 17–18
research
  establishments, Africa 59–61
  post-Green Revolution 109
  priorities 60–1, 156, 161
  staff shortages 7
resistant cattle breeds, trypanosomiasis 51

resistant plant varieties 108–9, 161
  in Africa 13–14
  alfalfa 132
  cassava 34–5
  coffee 46
  cotton 43
  maize 50
  millet 27
  rice 37, 84–5
rice 107–8
  biological diversity 85
  IPM in Africa 36–9
  IPM in Asia 82–9
    national programmes 85–9
    regional programmes 89
  major pests 36, 83
  pesticide use 75–6, 83–5, 87–9
  resistant varieties 37, 84–5
rice tungro virus (RTV) 83, 87
rodents 83
Rodolia iceryae 46
Rodolia rufopilosa 103
rotation, crop 14
rubber 100
Rwanda 50

Sacadores pyralis 136
Sahel
  CILSS/FAO project 20–3, 25
  pearl millet IPM 25–9
  sorghum pests 30
Saissetia oleae 144
scale
  armoured 17
  fried egg 45
  soft 17
  soft green 45
Scirpophaga 83
Scirpophaga excerptalia 99
Scirpophaga innotata 87
Sclerospora graminicola 26
scouring system, pest 149, 161
  cotton 41
  rice 39
Scrobipalpuloides absoluta 141–2
seeds
  fungicide treatment 19
  mixtures 4
Semiothisa abyata 139
Sesamia 30, 83
Sesamia calamistis 17, 23, 26
share-croppers 2
shootfly, sorghum 23, 30
Sitobium avenae 143, 144
soil degradation 107–8
sorghum 2, 23, 29–30
South America 121–49, 159–60
  agricultural overview 122–5
  constraints to IPM use 146–7
  future prospects 147–9
  IPM development and
      implementation 129–31
  new ongoing IPM projects 145
  pesticide use 125–9, 159
  regional IPM programmes 131–45
soybean 123–4, 128–9, 137–9, 160
Spodoptera 26, 92–3, 102, 106, 136
Spodoptera frugiperda 145
Spodoptra exigua 91
Sri Lanka 81
staff
  education 59
  extension 7, 59
  shortages 7, 156
stemborers
  cocoa 48
  maize 23
  millet 26
  rice 36, 38, 83
  sorghum 23, 30
  sugarcane 17, 99
  white 87
stink bugs 137, 138
stored products 56, 162
Striga 22, 28, 30, 83
Striga hermonthica 24, 26, 30
subsidies, pesticide 160
  in Africa 5, 61
  in Asia 72, 87, 102, 109
  withdrawal 85, 88
subsistence farming 4
Sudan 40–4, 61
sugarcane
  in Asia 17, 98–100

in South America 123, 129, 139–41
surveillance systems, pest 19, 71, 102, 157, 161
sweet potato 13
swollen shoot virus 47–8
Sylvania molesta 103
systems management 147–8, 161

Telenomus remus 131, 136
Teleonemia scrupulosa 55
tenants 2
Teretriosoma nigrescens 56
terracing 4
Tetranychus urticae 144
Thailand 71–2, 78, 81, 98
Theobroma cacao (cocoa) 47–9, 100
threshold systems, pest 19, 72–3, 162
  cotton 41
  rice 37
Thrips palmi 91
Togo 17–18, 45
Tolyposporium penicillariae 26
tomato 141–2
traditional pest control practices 3–4, 28
training 7, 59
  of farmers 24, 59, 157
  in pesticide handling 19
trap crops 94
trees
  cropping systems and 54–5
  as weeds 55–6
Trichogramma
  in Africa 18
  in Asia 95, 99, 102, 103
  in South America 130–1, 136, 139, 149
Trichogramma chilonis 99
Trichogramma jagonicum 99
Trichogramma minutum 141
Trichogramma praetiorum 43
Trichogramma pretiosum 135, 140, 142
Trichogrammatoidea bactrae 93
Trissolcus basalis 138
trypanosomiasis, in cattle 50–3
tsetse fly control 50–3

Umubano 50
United States Agency for International Development (USAID) 12, 21

vectors, biological control 52–3
vegetables
  in Africa 53
  in Asia 75, 90–4
velvetbean caterpillar 137
Venezuela 131, 136, 141

Wageningen Agricultural University, Netherlands 7, 12
weaverbirds 54
weed control 162
  in Africa 15–16
  biological 102–3
  cassava 35–6
  cotton 40
  millet 27–8
  rice 37–8
  in South America 127
West African Rice Development Association (WARDA) 37–8
wheat 108, 122–3, 129, 142–3
whitefly (*Bemisia tabaci*) 32, 40–2, 44, 95
white grub 17
wilt, cotton 40
witchweed, *see Striga*
women 2, 59

Xanthomonas campestris pv. *manihotis* 32
Xanthomonas malvacearum 40

Zimbabwe 45

Index compiled by Liza Weinkove

Integrated Pest Management in the Tropics

Current Status and Future Prospects

The concept of Integrated Pest Management (IPM) was developed as an alternative to chemical pesticides following the widespread realization of their horrifying and damaging effects on environment, human, animal and plant health, which were vividly portrayed in Rachel Carson's book *Silent Spring*. The IPM approach involves the use of different tactics in compatible combinations to keep pest populations below the levels at which they cause economic injury. Thus, the IPM approach minimizes the use of chemical pesticides and avoids their harmful effects.

The development and implementation of IPM has been increasing in North America with successful results. However, its role in tropical agriculture is less well known. For this reason, the United Nations Environment Programme (UNEP), and the International Centre for Insect Physiology and Ecology (ICIPE) undertook a global review of IPM to assess the impact of related activities in tropical regions of Asia, Africa and South America. This volume assesses the current status and future prospects for IPM in these regions. It provides a unique overview of the efforts made to develop and implement IPM for the pests of livestock and agroforestry in selected countries in the tropics (including India and China), as well as a survey of IPM strategies on a crop-by-crop basis for each continent. The book gives an honest appraisal of both the successes and failures of past IPM programmes and provides new paradigms and directions that IPM must develop, if it is to be adopted by farmers and governments on a scale necessary to change their current reliance on chemical pesticides.

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