Evaluating farmers' knowledge, perceptions and practices: a case study of pest management by fruit farmers in the Mekong Delta, Vietnam

Promotor: dr. J. C. van Lenteren
Hoogleraar in de Entomologie

Co-promotor: dr. A. van Huis
Universitair Hoofddocent Tropische Entomologie

Paul Van Mele

Evaluating farmers' knowledge, perceptions and practices: a case study of pest management by fruit farmers in the Mekong Delta, Vietnam

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
dr. ir. L. Speelman,
in het openbaar te verdedigen
op maandag 4 september 2000
des namiddags om half twee in de Aula

Van Mele, P.

Evaluating farmers' knowledge, perceptions and practices: a case study of pest management by fruit farmers in the Mekong Delta, Vietnam /
Paul Van Mele. – [S.1.:s.n.] – ill.
Doctoral thesis Wageningen University, the Netherlands. – With ref. – With summary in Dutch.

ISBN 90-5808-267-9
Subject headings: agricultural knowledge systems / fruit pests / conservation biological control / predation / ants

Current studies have been initiated within the Vlaamse Interuniversitaire Raad (VLIR) project 'Integrated Pest Management in Fruit Production' at the Cantho University (CTU), Vietnam, in co-operation with the Catholic University Leuven (KU Leuven), Belgium. This project has been funded by the Belgian Administration for Development Co-operation (BADC).

The cover illustrates the agricultural landscape at Tien Giang Province, the Mekong Delta, Vietnam. Rice is drying on the road while the next crop has already been planted. Behind this, a paddy field has been recently converted into an orchard by making planting heaps from the collected top soil. At the back, non-crop trees can be observed. Back cover insets: *Oecophylla smaragdina* nest in a citrus tree (top), a fruit farmer mixing pesticides (bottom). Photographs: P. Van Mele

Printed by Walleyndruk NV, Brugge, Belgium
Copies can be ordered from the author at p.vanmele@cabi.org

Stellingen behorende bij het proefschrift
"Evaluating farmers' knowledge, perceptions and practices:
a case study of pest management by fruit farmers in the Mekong Delta, Vietnam"
van Paul Van Mele

1. Mieren in boomgaarden hebben onvermijdelijk een toename van suikerafscheidende insecten tot gevolg, hetgeen betekent dat ze niet altijd goede biologische bestrijders zijn.
   Dit proefschrift
   Khoo, K. C., Ooi, P. A. C. and Ho, C. T. 1993. Crop Pests and Their Management in Malaysia. Tropical Press Sdn. Bhd., Kuala Lumpur, pp. 242.

2. Een betere herkenning van moeilijk waar te nemen plaagorganismen in een gewas leidt niet noodzakelijk tot een beter beredeneerde gewasbescherming.
   Dit proefschrift

3. De aanwezigheid van goed zichtbare natuurlijke vijanden in een agroecosysteem is de beste motivatie voor boeren om minder of geen pesticiden te gebruiken.
   Dit proefschrift

4. Experimenten van onderzoekers uitgevoerd op het boerenbedrijf schieten vaak hun doel voorbij, omdat hierbij alleen gebruik gemaakt wordt van het land en het gewas van de boer, maar niet van diens kennis.
   Dit proefschrift

5. Biologische diversiteit vormt een belangrijke, tot nu toe onderbenutte rijkdom voor Vietnam, die heden ten dage verloren dreigt te gaan door een beleid dat zich voornamelijk richt op productie van meer voedsel.
   Dit proefschrift

6. Het communisme heeft er in Vietnam toe geleid dat alle boeren gelijke kansen hebben op het verkrijgen van informatie.

7. Eenzijdige landbouwvoorlichting is oplichting.

8. Vernieuwing is niet altijd vooruitgang.
   G. van Istendael. De Morgen, 04/05/2000

9. Doordat universiteiten voor hun financiering in toenemende mate afhankelijk zijn van derde geldstromen is het realiseren van een duurzaam beleid voor ontwikkelingssamenwerking steeds moeilijker.

10. Nationale instituten in ontwikkelingslanden doen voornamelijk vraaggedreven onderzoek met een grote relevantie voor de lokale boeren, een benadering die helaas vaak wordt verlaten wanneer die instituten gaan samenwerken met Westerse universiteiten.

11. Zintuiglijke waarneming is het begin van alles.

12. Interbrew heeft een beter gevoel voor smaak dan Heineken omdat Interbrew bij de productie rekening houdt met lokale tradities en gebruiken.

Abstract

After the *Doi moi* policy reform of Vietnam in 1986, the government has increasingly emphasized diversification of agricultural production into high value crops. Over the period 1985-1995, fruit production in the Mekong Delta increased from 92,100 to 175,700 ha mainly due to better land tenure security. However, the potential of the fruit industry is not yet fully exploited. Our surveys have indicated that, besides pest and disease problems, fruit farmers lack an efficient marketing, credit and transport system. The agro-business has quickly responded to the government's policy reform. Pesticides and chemical fertilizers have become increasingly important at the expense of traditional practices of biological control. This study has tried to assess the agronomic, economic and social conditions influencing farmers' knowledge, perceptions and practices in pest management. Case studies are presented for mango, citrus and sapodilla.

The ease of observation is an important aspect contributing to farmers' knowledge and perception of pests. As for rice, fruit farmers readily targeted pests such as leaf-feeding insects, which cause conspicuous damage symptoms. Cultivation practices may interfere with pest monitoring. Because mango trees are never shaped by pruning and trimming, trees often grow 8 m high or more. Therefore, damage of the mango seed borer *Deanolis albizonalis* (Lepidoptera: Pyralidae) was often wrongly attributed to the fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae), a situation which has recently improved due to extension and media activities. Citrus farmers have learnt about the existence of difficult-to-observe pests, such as the citrus red mite *Panonychus citri* (Acarina: Tetranychidae) and thrips (Thysanoptera: *Thrips* sp. and *Scirtothrips* sp.) through pesticide advertising campaigns by the Extension Service or through farmer-to-farmer promotion of certain acaricide products.

Those fruit farmers knowing about natural enemies have acquired this knowledge only by observing their own orchard and refrained from applying pesticides on a calendar basis, which is commonly practiced by most other fruit farmers. However, because orchards are relatively closed habitats and competition between farmers is high, farmer-to-farmer information exchange about advanced farming techniques, including the manipulation of predatory ants, is quite uncommon. In 1998, about 75% of the sweet orange (*C sinensis*) and 25% of the Tieu mandarin (*C. reticulata*) orchards had large weaver ant *Oecophylla smaragdina* (Hymenoptera: Formicidae) populations, due to a lower pesticide pressure in the first crop. In citrus orchards with *O. smaragdina* fewer pesticide sprays and chemical fertilizers were used without affecting either the yield or the farmers' income.

Farmers relying on pesticide advice from the media advertisements sprayed insecticides more frequently and applied more different products, whereas the extension has stimulated the use of acaricides and increased the number of both insecticide and fungicide sprays. The traditional practice of biological control with *O. smaragdina* might be endangered with growing media influence and when extension activities remain confined to chemical pest control. Citrus farmers with *O. smaragdina* or sapodilla farmers with the black ant *Dolichoderus thoracicus* (Hymenoptera: Formicidae) in their orchard all used fewer highly toxic WHO Category I insecticides than those without ants. The majority (61%) of sapodilla farmers considered *D. thoracicus* as beneficial in decreasing damage by the fruit borer *Alophia* sp. (Lepidoptera: Pyralidae). Promoting wider use of *D. thoracicus* may be difficult, because 30% of the farmers said that this ant increases populations of the mealybug *Planococcus lilacinus* (Homoptera: Pseudococcidae). In six on-farm experiments, the mealybug *P. lilacinus* was not affected by *D. thoracicus*, but *Alophia* sp. populations were significantly smaller in ant-abundant trees.

By evaluating fruit farmers' knowledge, perceptions and pest management practices with a systems approach, this study has identified weaknesses and strengths for the development of IPM fruit programmes in Vietnam, which could also provide information to improve fruit pest management in other tropical countries.

Key words: *Deanolis albizonalis*, *Alophia* sp., *Planococcus lilacinus*, *Panonychus citri*, *Dolichoderus thoracicus*, *Oecophylla smaragdina*, Vietnam, natural enemies, pesticides, agricultural knowledge systems

Acknowledgements

Many people have contributed to the completion of this thesis. First I would like to thank Prof. Joop van Lenteren and Dr. Arnold van Huis for their critical comments and useful suggestions throughout last year's work of analyzing, interpreting and writing. Together with their help and that of Gerard Pesch, Frans Meerman and Marieke Bosman, all from the Laboratory of Entomology at the Wageningen University, a highly efficient support and feed-back system has been created between my home base in Belgium and the Netherlands.

Current studies have been conducted within the 'Integrated Pest Management (IPM) in Fruit Production' Project at the Cantho University (CTU), Vietnam, in co-operation with the Catholic University Leuven (KU Leuven), Belgium. This Project has been funded by the Belgian Administration for Development Co-operation (BADC). I am very grateful to Prof. Jef Coosemans from the Laboratory of Phytopathology and Plant Protection, KU Leuven, for his confidence and for providing me the opportunity to start-up this project under his supervision. The difficult task to establish a new project in the tropics, and more particularly in Vietnam, would have been impossible without his scientific and diplomatic support. During my period in Vietnam, I was also given the chance to gain experience during several international fora in other SE Asian countries, making me little by little a 'young IPM expert' for tropical fruit crops. These occasions and exposures have strengthened my confidence for writing this thesis. Prof. Johan Billen of the Zoological Institute at the KU Leuven, is acknowledged for the interesting and enthousiastic discussions on the weaver ant *Oecophylla smaragdina*.

At the CTU, many people have contributed, directly or indirectly, to the success of the 'IPM in Fruit Production' Project. I wish to acknowledge:

- Prof. Tuan, co-ordinator of the IPM Project and rector of the CTU, and Prof. Kim, vice co-ordinator, for administrative assistance and organizing workshops and meetings, and for developing workplans of the Project;
- Prof. Thu Cuc, for transferring her enthusiasm of working with farmers and predatory ants, for learning me to be (even more) patient, and for motivating me to write this PhD-thesis;
- Dr. Hai, secretary of the Project, for the administrative and practical help, and for the good times;
- Mai, for the numerous telephones, arranging the field visits and encoding the survey data with the required discipline;

- Dr. Huynh, Dr. Sen, Thu Thuy, Nghiem, Oanh, Phen, Minh, Hau and other colleagues for the numerous discussions while having a coffee or *da chanh*;
- Nham, Thu Ga and all the other staff and students for helping with the on-farm experiments;
- Prof. Ren, Head of the Department of Soil Science, for providing agro-ecological maps and for the fruitful discussion on soil fertility problems related to diseases;
- Prof. Ve, Head of the Department of Crop Science, for helping me to situate fruit farmers' problems in a broader farming systems research (FSR) context and for the many good laughs;
- Besides, I would like to thank all the CTU staff who assisted during the survey, as well as all the participating farmers. Without their contributions there would not be an acknowledgement.

Other people in Vietnam to be thanked are Nico Vromant, from the Mekong Delta Farming Systems Institute, Can Tho, and Patricia Matteson from the Food and Agriculture Organization of the United Nations (FAO), Hanoi for reviewing some of the chapters, as well as Piet Segeren and Rinie van den Oever for providing me with interesting new insights. I would also like to show my appreciation to Karel Cools and Paul Verle from the Belgian Embassy in Hanoi for their hospitality and enthusiasm in further supporting farmer workshops on the the use of ants as biological control agents. Dr. Pham Van Lam (Biological Control Research Centre, Hanoi), Dr. Ngo Tien Dung (National IPM Programme), Dr. Huynh Tri Duc (Southern Fruit Research Institute, Long Dinh) and Mr. Nguyen Huu Huan and Pham Minh Sang (Pesticides Control Centre South Vietnam), as well as all the staff from the Extension Service and Plant Protection Department from Can Tho, Dong Thap and Tien Giang Provinces have all contributed to making this thesis a more valuable document.

At the Ghent University, Belgium, several persons have assisted to finalize this work. Prof. Patrick De Clercq and Dr. Mark Van de Veire, Laboratory of Entomology, gave interesting suggestions and comments on several aspects of integrated pest management in fruit crops. Prof. Paul Goetghebeur from the Laboratory of Plant Morphology is kindly acknowledged for his advice on the influence of plant phenology and morphology on insect pests and natural enemies, and Olivier Thas of the Department of Applied Mathematics, Biometrics and Process Control for help with statistical analysis. Tom Lauwaerts greatly helped with the layout.

This thesis further benefitted from discussions with K. L. Heong (IRRI, the Philippines), K. C. Khoo (Universiti Putra Malaysia), and from several people from Australia:

Geoff Waite (Queensland Department of Primary Industries), Dan Papacek (Bugs for Bugs), Andrew Beattie (University of Western Sydney), R. K. Peng (Northern Territory University) and D. K. Waterhouse (ACIAR). Prof. Way (Imperial College, U.K.) critically reviewed several of the chapters on ants. Additional, interesting grey literature was provided by Anthony Little (CABI Bioscience, U.K.), Arthur DelVecchio (GTZ, Thailand), Peter Hegenbarth (Economic and Social Commission for Asia and the Pacific, United Nations, Thailand), and Lars Hein (FAO, Italy).

And last but not least I would like to thank my wife Marcella and our family, as well as all the friends who made life abroad and in Belgium more joyable and interesting.

Table of contents

Abbreviations and acronyms

ACIAR	Australian Centre for International Agricultural Research
AD	*anno domini* (the year of the Lord, of the Christian era)
a.i.	active ingredient (pesticide)
BADC	Belgian Administration for Development Co-operation (renamed DGIS)
BPH	Brown planthopper (*Nilaparvata lugens*)
Bt	*Bacillus thuringiensis*
ca	*circa*
CABI	International Centre for Agriculture and Biosciences (former Commonwealth Agricultural Bureaux International) (U.K.)
CGD	Citrus greening disease
CGIAR	Consultative Group for International Agricultural Research
CIDSE	International Committee for Solidarity and Development
CIP	International Potato Center (Peru)
CIRAD	International Centre for Rural and Agricultural Development Research (France)
CLM	Citrus leafminer (*Phyllocnistis citrella*)
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
CTA	Technical Centre for Agricultural and Rural Co-operation (Africa, Caribbean, Pacific countries – EEC)
CTU	Cantho University (Vietnam)
CTV	Citrus tristeza virus
DAFF	Department of Agriculture, Forestry and Fisheries (Vietnam)
DANIDA	Danish International Development Agency
DGIS	Directorate-General for International Co-operation, Ministry of Foreign Affairs, Belgium
DOA	Department of Agriculture (Thailand)
DOAE	Department of Agricultural Extension (Thailand)
dong	Vietnamese currency (1US$ = 13,500 dong, 1998)
DPI	Department of Primary Industries (Australia)
EC	European Commission
ES	Extension Service
ESCAP	Economic and Social Commision for Asia and the Pacific

FAO	Food and Agriculture Organization of the United Nations
FEER	Far Eastern Economic Review
FFS	Farmer Field Schools (agricultural extension)
FO	Farmers' Organization
FPR	Farmer Participatory Research
FSR	Farming Systems Research
GDP	Gross Domestic Product
GTZ	Deutsche Geselschaft für Technische Zusammenarbeit, German Agency for Development Co-operation
ha	hectare (10,000 square metres)
HA	Horticultural Association
HYV	High Yielding Varieties
IFS	Integrated Farming Systems
IOBC	International Organization for Biological Control of Noxious Animals and Plants
ICM	Integrated Crop Management
IPC	Integrated Pest Control
IPM	Integrated Pest Management
IRRI	International Rice Research Institute (the Philippines)
JICA	Japanese International Co-operation Agency
KPP	Knowledge, Perceptions and Practices
KU Leuven	Catholic University Leuven (Belgium)
MAFI	Ministry of Agriculture and Food Industry (Vietnam)
MARD	Ministry of Agriculture and Rural Development (Vietnam)
MD	Mekong Delta
MRL	Maximum Residue Limit (pesticides)
NGO	Non-governmental Organization
NIPP	National Institute of Plant Protection (Vietnam)
NRI	Natural Resources Institute (U.K.)
pers. comm.	personal communication
PPD	Plant Protection Department, MARD
PPSD	Plant Protection Sub-Department, MARD
PSO	Petroleum Spray Oils
RAAKS	Rapid Appraisal of Agricultural Knowledge Systems

R&D	Research and Development
SE	South-East
SOFRI	Southern Fruit Research Institute (Vietnam)
T&V	Training and Visit (agricultural extension)
TOT	Transfer of Technology (agricultural extension)
UNDP	United Nations Development Programme
USSR	United Sovjet Socialist Republics
VLIR	Vlaamse Interuniversitaire Raad (Flemish Inter-university Council for Development Co-operation, Belgium)
VNBCRC	Vietnam Biological Control Research Centre
VNS	Viet Nam News
WHO	World Health Organization

1. Introduction

1.1. Fruit production in Vietnam

1.1.1. Agriculture in Vietnam

The Vietnamese economy relies mainly on agriculture with more than 50 million people (70% of the total national population) living on about 11 million ha of cultivated land (one-third of the national area) (DAFF, 1996). Vietnam is divided into seven agricultural zones (Figure 1.1.1.a.). Traditionally, crops are often integrated with livestock and fish production. Rice has always been the most important component, accounting for *ca* 65% of the total cultivated area in 1995 (Figure 1.1.1.b).

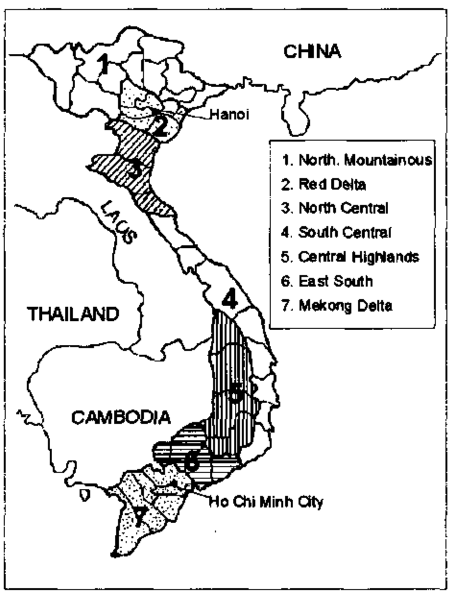

Figure 1.1.1.a. Agricultural zones in Vietnam.

Rice production between 1970 and 1980 remained rather low at around 11 million tonnes per year. With the introduction of the Contract system (see below) in 1981, production increased by *ca* 30% after which it stabilized due to a lack of farmers incentives and motivation (Sanh *et al.*, 1998). Until the late 1980s, Vietnam was obliged to import rice and it was not until after the *Doi moi* policy reform of Vietnam in 1986, that agricultural production was decollectivized and rice production doubled to *ca* 24 million tonnes in 1995. Since 1990, Vietnam has become the third largest rice exporter in the world after Thailand

and the United States. Rice productivity has further increased from 3.6 tonnes per ha in 1995 to 4.8 tonnes in 1999 (VNS, 2000a).

Over the past 10 years, the total agricultural crop production in Vietnam has grown at an annual rate of 5.2% (FEER, 1999), with an annual population growth of 1.7% (VNS, 2000b). This increased production has been mainly achieved through rice by introducing high-yielding varieties (HYV) and government support to intensify production. Fertilizer and pesticide use has increased due to the national agricultural policy and aggressive advertising and marketing techniques of the agro-business (Heong *et al.*, 1994). Similar to other SE Asian countries that introduced Green Revolution technologies, farmers got convinced that they were likely to loose their crop if they did not apply pesticides (Oudejans, 1999).

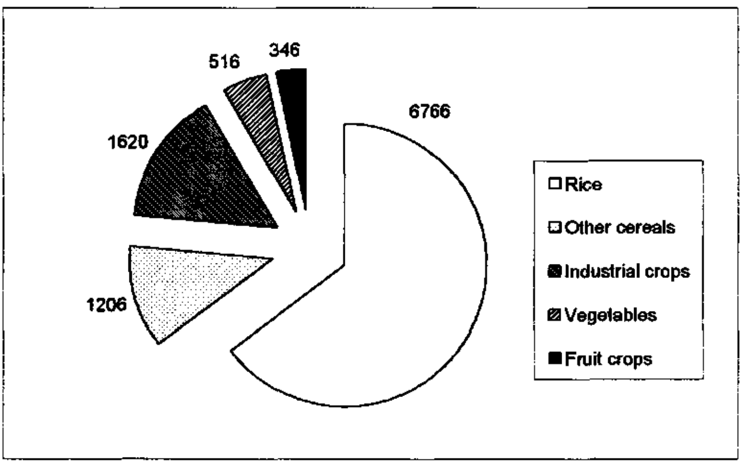

Figure 1.1.1.b. Major crops (in thousands of ha) in Vietnam (source: DAFF, 1996).

1.1.2. Importance of fruits in the national economy

Since the *Doi moi*, government policies have increasingly emphasized diversification of agricultural production including high value crops. The possibility of getting relatively long land leases has encouraged farmers to invest in their land. Land is still property of the State, but farmers can buy the authorization to cultivate their piece of land, ranging from 20 years for annual crops to 50 years for perennial crops. The assignment of land on the basis of renewable leases is to the family rather than to the individual (Pingali and Xuan, 1992).

Land use and crop choice decisions are no longer made by the government. Although conversion of paddy fields into orchards has not been actively promoted, the higher net profits from orchards, being five to ten times more than could be achieved on the same area of land under rice production, together with an increased land tenure security has attracted many farmers to invest in orchards. However, as costs for establishing new orchards are very high, *ca* 420 to 580 US$ per ha, with Vietnam having a gross domestic product (GDP) of 200 US$ per capita, mainly the richer farmers have been able to convert part or all of their paddy fields into orchards. For example, nearly 95% of about 200 women interviewed in Omon District indicated a lack of capital for converting their paddy field into orchards as their major problem (Chi *et al.*, 1995). Renewal of older mixed fruit gardens under polyculture into both more commercially oriented orchards under oligoculture (two or three fruit species belonging to the same genus, often combined with some non-crop trees) and monoculture, has received government support such as reduced interest rates on agricultural loans. Besides, farmers do not have to pay taxes during the first three years of investment for 'modernizing' their orchard or bringing wasteland under fruit cultivation (Dang, 1997).

Under these conditions, the fruit growing area in Vietnam has increased from 218,000 in 1985 to 346,000 ha in 1995 (DAFF, 1996). As the statistical data only take into account orchards which are not under polyculture, one should double the area under cultivation to have a more realistic figure of the importance of fruits in the economy (Cao-Van *et al.*, 1997). The past and prospected evolution of fruit production in the different regions is given in Figure 1.1.2. In recent years, the annual rate of increase in area with fruit crops is 6.2% and policy planners expect one million ha for the next decade (Luat, 1998).

According to the Ministry of Agriculture and Rural Development (MARD), the average per capita consumption is *ca* 40 kg of fruits per year (Luat, 1998). A study conducted by the Worldbank in 1993, estimated per capita fruit production in Vietnam at 61 kg per year, compared to 104 kg in Thailand, 114 kg in the Philippines, 11 kg in China and 36 kg in Laos (Singh, 1993). China, Laos and Cambodia are considered to become increasingly important export markets for mango (*Mangifera indica* L., Anacardiaceae) and citrus (*Citrus* spp., Rutaceae) in the near future (Chau, 1998).

A major increase in area under fruit cultivation is expected for the Northern Mountains and Midlands, where population pressure is relatively low compared to the Red River and Mekong Delta with a population density of more than 400 people per square km. In 1995, in these Northern Mountains and Midlands, citrus was cultivated on *ca* 7,800 ha, and on a smaller acreage, *ca* 3,800 ha in the Red River Delta (DAFF, 1996).

The national fruit production has augmented from *ca* 2.6 million tonnes in 1994 to 3.8 million tonnes in 1997 (Luat, 1998). From 1995 to 1998, the area of citrus cultivation increased from 55,600 ha to 67,500 ha, while the area of fruit from the Sapindaceae family, namely longan (*Dimocarpus longan* Lour.), rambutan (*Nephelium lappaceum* L.) and litchi (*Litchi chinensis* Sonn.), expanded from 37,600 to 93,000 ha (DAFF, 1999).

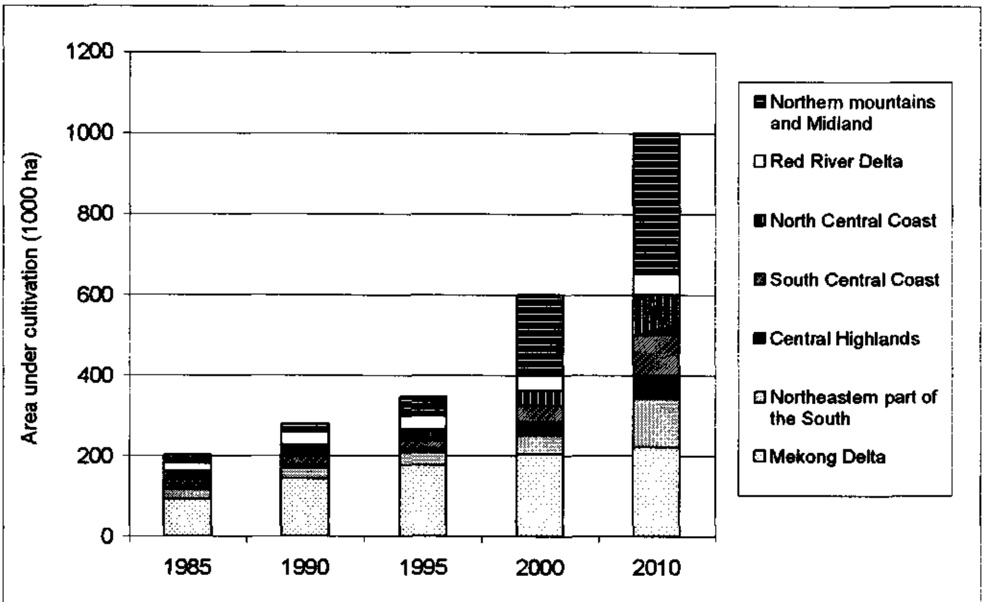

Figure 1.1.2. Past and prospected evolution of area under fruit cultivation (excluding orchards under polyculture) from 1985 to 2010 in Vietnam (source: Daff, 1996 and Chau, 1998).

Sustainability in fruit production will become an increasingly important issue, especially since the government has put the target for the next decade at 12 million tonnes of fruit per year (Chau, 1998). The local market mainly grows in the cities due to improving living standards. Before 1990, *ca* 98% of the export went to the United Sovjet Socialist Republics (USSR) and consisted of bananas, pineapple and citrus. This decreased in 1995 to *ca* 22%. Export of fresh fruit is now mainly limited to neighbouring countries such as China (Hongkong), Taiwan and Singapore, and to a lesser extent to Australia. The major export product is dragon fruit (*Hylocereus undatus* (Haw.) Britton & Rose, Cactaceae), which is mainly grown in South-Central Vietnam. Mango is only sold to Hongkong and Australia (Chau, 1998). Due to the general poor fruit quality and lack of uniformity, Vietnam cannot compete with Thailand in the export of mangoes. Some delicious mango varieties such as *Xoai cat hoa loc* face problems of transportation because it has a very thin skin. Furthermore, production costs are higher compared to those in Thailand and India. In 1997, Vietnam exported *ca* 6,000 tonnes of fresh fruit (only 0.17% of the total production) with a value of 68 million US$ (Luat, 1998), *ca* one tenth of the value from exported fruit obtained in Thailand (Hong, 1998).

Both the total fruit production and export could be further increased when polyculture and monoculture orchards are intensified, and when both the quality and efficiency of production is raised. Improved fruit quality also implies that pesticide residues are kept below the permitted maximum residue limit (MRL). This is especially important when aiming at export to industrialized countries, considering their strict inspection procedures. These targets can only be met when sufficient policy support is given to proper land use planning (where to grow what, and how much), to increased research and extension related to crop production and crop protection, as well as to improved processing and marketing (Chau, 1998).

1.1.3. Fruit production in the Mekong Delta (MD)

Over the period 1985-1995, fruit production in the Mekong Delta (MD) increased from 92,100 to 175,700 ha (DAFF, 1996). The potential of fruit production in the MD is, however, not yet fully exploited. As the population pressure is high and the government wants to safeguard Vietnam's position on the rice export market together with local food security, increased fruit production in the Mekong Delta will need to focus on improved production efficiency rather than on increased area under cultivation (see Figure 1.1.2.).

In 1995, citrus was the major fruit crop in the MD, being cultivated on an area of 38,000 ha (Table 1.1.3). The major fruit producing provinces are given in Figure 1.1.3. The land under citrus cultivation has strongly increased since the early 1990s. The very fast growing demand for citrus planting material attracted many farmers and nurserymen to start a local business. This production and spread of uncertified planting material, many of which were already infested with citrus greening disease before being actually planted, has been described by Aubert (1990) as one of the major problems for the citrus industry in the whole of Asia. Similarly, in Vietnam, most citrus trees are from cuttings. Major species are sweet orange (*Citrus sinensis* (L.) Osbeck), Tieu mandarin and sweet mandarin (*C. reticulata* Blanco), and to a lesser extent king orange (*C. nobilis* Lour.) and pummelo (*C. maxima* (Burm.) Merr.). Lime trees (*C. aurantiifolia* (Christm.) Swingle) are often found around these citrus orchards. Nearly all citrus is for the local market and for the markets in Ho Chi Minh City and Hanoi.

Table 1.1.3. Area under fruit cultivation (in ha) in the major fruit growing provinces of the Mekong Delta, 1998 (source: Chau, 1998).

Crop	Tien Giang	Can Tho	Dong Thap	Ben Tre	Vinh Long	Tra Vinh	Total[2]
Citrus	1,151	13,320	2,940	8,078	7,352	1,774	37,973
Longan	8,413	1,300	3,000	6,335	6,689	425	28,633
Banana	335	3,420	3,250	1,729	2,162	3,454	27,921
Pineapple	4,900	1,311	-	-	-	-	17,962
Mango	2,414	2,403	3,500	345	2,087	885	12,706
Rambutan	850	-	-	2,349	659	265	4,423
Sapodilla	1,056	200	-	-	-	668	3,724
Durian	844	400	-	-	365	40	1,908
Total[1]	37,433	30,769	16,426	25,189	25,980	15,550	218,951

[1]Including area of all other fruit crops which are not mentioned in the table.
[2]Including area of all other provinces in the Mekong Delta which are not mentioned in the table.

After citrus, longan is the second most important perennial fruit crop of the MD, being cultivated over an area of 28,600 ha and with an average yield of 10 tonnes per ha (DAFF, 1996). It belongs to the Sapindaceae family and is as such related to rambutan and litchi, the latter being an important crop in the north of the country. Longan is almost only cultivated in the MD, where it is a crop of increasing importance. The area of cultivation expanded from 11,800 ha in 1995 to 37,000 ha in 1998 (DAFF, 1999). In 1998, two-thirds of the established longan orchards were converted paddy fields, whereas up to 25% were converted from other orchards, mainly citrus. Citrus, mango and durian (*Durio zibethinus* Murray, Bombacaceae) orchards were generally older and nearly all originated from paddy fields. This illustrates that most orchards are established without government assistance, and that support to convert less productive polyculture orchards in more commercial orchards has mainly led to an increase in longan production.

Longan is typically cultivated as a monocrop. Major varieties cultivated are *Nhan long* and to a lesser extent *Nhan tieu la bau*. Farmers presently prefer to grow longan as trees start bearing fruit within two years after planting, giving them a fast return of investment. In old mango and durian orchards it has been observed that farmers plant longan as an intercrop, and cut the old trees once the longan becomes productive. Flowering is induced by girdling, which enables farmers to harvest twice a year, once on-season from May to August, and once off-season from December to April, depending on the region and variety cultivated.

Longan farmers are highly market oriented and often aim at short-term moneymaking. They are highly responsive to commercial advertisements by the agro-business and use high amounts of pesticides and fertilizers. During our survey in 1997-1998, some farmers even reported spraying insecticides up to 48 times per year. As export markets, and especially those of developed countries, have high quality requirements, pesticide use will definitely have to be reduced to stay below the MRLs. Another fact calling for the necessity to reduce pesticide use in this crop is the direct health hazard for the local population. Many people, both in the cities and the countryside, put the fruit directly in their mouth to avoid that the juice would stick to their hands when opening the thin peel. Especially when fruits are not washed thoroughly, people ingest a lot of pesticide residues. Although it would be interesting to investigate potentials and constraints for developing an integrated pest management (IPM) programme in this crop, longan was not dealt with in this thesis. One reason for not including this economically important crop is that it has been introduced in the MD only recently, and that probably little empirical experience regarding pest management is available among longan farmers. Instead, we focused on those crops with a longer tradition of cultivation, namely citrus, mango and sapodilla.

After citrus and longan, mango is the third most important perennial fruit crop of the Mekong Delta, being cultivated over an area of 12,700 ha, and with an average yield of 9.3 tonnes per ha. In 1995, 66% of Vietnam's national gross output for mango was produced in the Mekong Delta (DAFF, 1996). Two outstanding clones, namely *Xoai cat hoa loc* and *Xoai cat chu* have been selected and registered by MARD in 1997 (Chau, 1998). Mango is a crop which has been cultivated in the Mekong Delta for a long time already, traditionally grown as polyculture (see next paragraph), but now more and more under oligo- or monoculture. A lack of proper trailing and pruning techniques has resulted in most trees being up to 8 m high or more, which consitutes a major problem for harvesting the fruits and for the monitoring and management of pests and diseases.

Sapodilla (*Manilkara zapota* (L.) P. van Royen, Sapotaceae) is being cultivated in many parts of the tropical world, including SE Asia. In the Mekong Delta, Vietnam, it is the fourth most important perennial fruit crop, following citrus, mango and longan, and has a total production area of 3,700 ha.

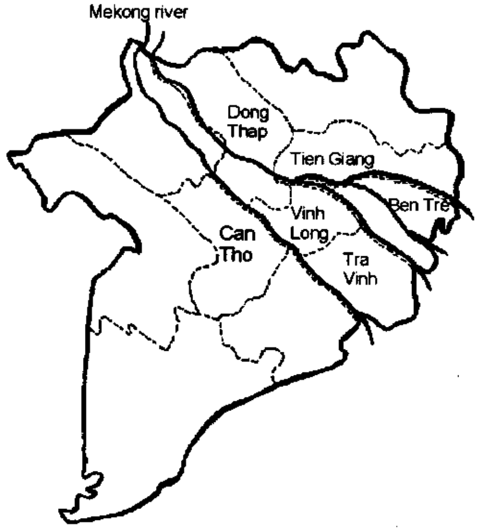

Figure 1.1.3. Major fruit producing provinces in the Mekong Delta, Vietnam.

1.1.4. Farming systems in the MD

1.1.4.1. Historical background

An overview of major events contributing to the current situation of the agricultural environment is given in Box 1.1.4.

1.1.4.2. High external input systems and integrated farming systems: which way to go?

In the Mekong Delta, Vietnam, integrated farming systems have existed for a long time. However, many farms have completely changed since the *Doi moi* policy reform in 1986 and traditional practices have often been neglected by farmers and government officials. As the output market was privatized and input supply decentralized, and farmers were able to obtain relatively long term, inheritable leases on their land, farm activities shifted to intensive cultivation.

Box 1.1.4.

Major events affecting farming systems development in the Mekong Delta (Source: Sahn *et al.*, 1998).

Time line	Events
10,000 years ago	Formation of the Mekong Delta (MD) • The MD is covered by forest; • Pioneer Vietnamese settlements collect rice for food and cultivation.
1705-1858	The early stage of exploitation of the MD • Three main canals are excavated and land is reclaimed; • Floating rice cultivation is developed.
1858-1954	French colonial regime • Many canals are excavated for draining land for rice cultivation; • People settle nearby canals; • Traditional rice cultivation: transplanted local varieties with a very low input; • Fruit cultivation develops mainly as polycultures, including multi-purpose trees and spontaneous undergrowth is used as vegetables or for medicinal purposes.
1954-1975	Years of war
1966	• Introduction of high yielding rice varieties (IR5 and IR8);
>1968	• Shift from single rice cropping to double rice cropping;
1972	• Brown planthopper (BPH) outbreak.
1976-1977	Farmers return to village and rural areas for land reclamation • As the government aims at rice self sufficiency, it is strictly forbidden to construct raised beds; • Orchards are reconstructed on the higher elevated soils and along banks of rivers and canals; • Those who have saved enough money invest mainly in monocultures or oligocultures of citrus or mango. Fruit trees are planted on *ca* 50,000 to 60,000 ha.
1977-1979	Rice crop failures
1977	• BPH outbreak;
1978	• Large floodings;
1979	• Shifting from BPH sensitive to BPH tolerant rice varieties.
1979-1981	Collectivization • In the MD, collectivization is only made for purchasing inputs and marketing outputs, not for land. • Many main and secondary canals are dug; • Double rice cropping increases; • Redistribution of land to farmers; • Many new areas are exploited (including forests and acid sulphate soils) for rice production.
1982-1987	Contract system • Individual households sign a contract with a collective farm. • The contracted amount of output is sold to the state at a fixed price.
1988-now	*Doi moi* policy reform • Farmers are assigned long-term, inheritable leases on their land; • Replacement of contract system with a fixed land tax system; • Privatization of input and output market; • Government stimulates conversion of polyculture orchards to oligo- and monoculture orchards; • Most BPH resistant rice varieties become susceptible to BPH; • Conversion of paddy fields into raised bed orchards increases without government support; • From 1985 to 1995, fruit cultivation in the MD increased from 92,100 ha to 175,700 ha.

Paddy production increased from 6.9 million tonnes in 1985 to 12.8 million tonnes in 1995, accompanied by a strongly increased use of chemical inputs. Rice farmers usually spray as soon as they find any symptoms of pest damage, or they calendar-spray 5 to 20 times per season with broad-spectrum insecticides (Noda *et al.*, 1998). Water pollution, degrading biodiversity and socio-economic problems, such as the growing income gap between rich and poor farmers, have become increasingly stringent. Therefore, research on biodiversity, resource recycling, system efficiency and system capacity of traditional integrated farming systems, mainly rice-fish or rice-prawn systems, has received some attention since the early 1990s, both at the farming system level (Rothuis *et al.*, 1998; Xuan and Matsui, 1998) and at the component level (Vromant *et al.*, 1998). However, integration of fish still faces a lot of problems in intensive rice cropping systems using HYVs, partly because in these systems crops are kept weed free (Vromant, pers. comm., 2000).

In fruit cultivation a similar trend is observed as in rice, with a shift from a combination of local varieties to orchards with only one variety. These older, mixed orchards were mostly not intensively managed causing yields to be low. With economic benefit becoming an increasingly important criterion, farmers are more tempted to practice 'modern' agriculture with high external inputs. It is not yet recognized that traditional farmers' knowledge and practices offer great potential to be applied in intensive cropping systems with reduced costs for chemical inputs and without affecting yields.

1.1.4.3. Characteristics of farming systems in the MD

By law, each family can have a maximum of five ha of land. In practice, the farm size in the MD depends on the human population density and available land resources of each district or village. The average farm size is one ha with the smaller farms ranging from 0.5 to 0.6 ha. A typical farm consists of four components: (1) a homestead where animals and vegetables are grown for local consumption, (2) a fish pond, (3) canals and raised beds for cultivation of perennial trees, and (4) paddy fields, which are sometimes combined with prawn or fish culture.

In the orchards, on average 1,000 trees per ha are planted. Fruit trees have traditionally been planted on slightly higher soils and riverbanks, whereas over the past 10 years more and more moderately high and even lowland paddy fields have been converted to raised beds on which fruit trees are planted. The average orchard size is only *ca* 0.5 ha. However, in some places such as Chau Thanh District in Can Tho Province, average orchard size is larger than one ha. This is due to several factors. In Chau Thanh, the water level during the flooding season (September-November) is still low, there is no saline water intrusion during the dry season, and it is situated close to the most important floating market of the MD at Phung Hiep. These circumstances have resulted in most farmers getting a good income from fruit cultivation. Land is divided among the children when the parents become too old, and those smaller orchards cannot generate enough income anymore to sustain a newly established family. These young people prefer selling their piece of land and move to the cities such as Can Tho City. As such, the initially richer farmers see the chance to increase their land.

1.1.5. Management problems faced by fruit farmers in the MD

In Table 1.1.5. an overview is given of the management problems most frequently encountered by fruit farmers. These data were obtained from a farmer survey in three different provinces of the MD during the dry season of 1997-1998 (December-April). The sampling methodology is explained in some of the next paragraphs. Specific information on the methodology and type of questions included in the questionnaire is provided in each of the chapters.

Table 1.1.5. Percentage farmers reporting major management problems in the Mekong Delta, 1997-1998.

	Sweet orange *n*=57	Tieu mandarin *n*=82	Longan *n*=171	Mango *n*=93	Durian *n*=36
Marketing	73.7	90.2	84.2	79.6	50.0
Credit	61.4	37.8	40.9	49.5	41.7
Flood	54.4	31.7	31.0	36.6	30.6
Transport	28.1	19.5	9.4	8.6	5.6

Land-use decisions made by farmers in the MD are highly influenced by both crop yield and market price of their product. Le Coq *et al.* (1997) illustrated that several citrus farmers reacted very impulsive on a change in market price by cutting their trees and replanting the cleared land with a more profitable crop. In the past, farmers in the MD have faced major problems when the market price for coconut, cacao, kenaf and sugarcane steadily dropped to a level where it was no longer profitable to cultivate these crops. Fruit farmers now do not wait until they are broke. Many shift to another crop after the yield or price of their product remains low for one or two consecutive years.

Longan has known a tremendous increase in area of cultivation over the past five years (pers. observation). The crop is relatively easy to grow. Initially, those farmers knowing how to induce flowering got a very high income. At present, most farmers know about this technique and hence the large difference in market price for off-season and on-season fruit has mostly disappeared. In 1998, a crop failure in Thailand resulted in a high demand for Vietnamese longan from China, doubling the price from 1 US$ per kg to 2 US$ per kg. Many farmers reacted impulsively and converted their paddy field or changed their orchard into a longan monocrop. In 1999, more orchards came into production and since there was no more export market to China, the local markets got saturated with longan fruit. Consequently the price fell to an historical depth of only 0.1 to 0.2 US$ per kg fruit. Some farmers have since started intercropping mango and durian trees in their longan orchard in order to diversify their crop and spread risk and income.

Citrus became very popular in the early 1990s as the price was stable and yields could be obtained already within 2-3 years. Especially Tieu mandarin has been planted since fruits can be sold at a high price during the Vietnamese New Year called *Tet*. Provincial nurseries could not keep up with the demand for new citrus planting material, and many farmers started their own small nurseries. This lack of certification of planting material has definitely lead to the increased spread of the citrus greening disease (CGD), a serious problem for citrus in SE Asia (Aubert, 1990). Because quite some citrus orchards were affected by the CGD, they have since the mid-1990s been gradually replaced by other fruit crops, although no statistical data are available to support this. In 1997, the occurrence of a new fruit disease, namely black spot *Guignardia citricarpa* Kiely, reduced the market value of Tieu mandarin, and some of the orchards with severe disease problems were therefore converted to other crops.

The conversion of paddy fields to orchards is very capital intensive. Tieu mandarin has mainly been planted by rich farmers who received loans from banks more easily than poorer farmers, who planted sweet orange. Because recently established sweet orange orchards were more severely affected by the CGD than Tieu mandarin, mainly sweet orange farmers have faced problems to pay back their loans. Since 1998, agricultural banks in Can Tho, which is the main sweet orange cultivation area, stopped providing credit to fruit farmers.

Over the past 10 years and due to prospected high returns, fruit crops have increasingly been planted on soils that are not very suitable, for instance soils that are prone to the annual floods. Generally, flood is controlled individually by building bunds around the orchard. However, after the prolonged floods at the end of 1999, most Tieu mandarin trees in Dong Thap Province died. While anticipating scientific screening of the more flood-tolerant citrus rootstock *Poncirus trifoliata* (L.) Raf., a crop often opted for by farmers is longan, as it lacks any root rot diseases and has no problems with viruses or bacteria. Farmers in Can Tho generally prefer growing citrus, because they have a long tradition in citrus cultivation and because they believe that other fruit crops do not have a stable market price.

1.1.6. Major pest problems in fruit crops in the MD

Until very recently, research on fruit crops has been rather limited (see below). Only few reports are available on orchard pest problems. Virtually no data are available on yield losses due to pests. Some of the pests have even not yet been identified.

In citrus, one of the most important pests is the psyllid *Diaphorina citri* Kuwayama (Table 1.1.6.1.). This pest is a vector of the CGD. Although this vector was observed in Vietnam in 1991, citrus growers did not regard it as a spray target (Whittle, 1992). Besides, pesticide sprays appeared to cause outbreaks of the citrus red mite *Panonychus citri* (Mc Gregor). In Whittle's paper, thrips (Thysanoptera: *Thrips* sp. and *Scirtothrips* sp.) were not mentioned as a problem in citrus in Vietnam. Other major pests recorded in the Mekong Delta are the citrus stink bug *Rhynchocoris humeralis* (Thnb.), the aphids *Toxoptera aurantii* (Boyer de Fonscolombe) and *T. citricida* (Kirkaldy), the leafminer *Phyllocnistis citrella* Stainton and several other lepidopteran species (Whittle, 1992; Cuc *et al.*, 1998). Most of the insecticides used for leafminer control are incompatible with an integrated pest management programme (Whittle, 1992). This statement was confirmed by our studies from 1997 to 2000 (Chapter 7), although recently in some places new, more selective insecticides have entered the market.

The most important pests in longan are given in Table 1.1.6.2., but will not be further discussed as this crop is not covered within this work. Some of these pests have been described by CABI (1998).

Table 1.1.6.1. Major pest and disease problems in citrus in the Mekong Delta (Source: Whittle, 1992; Duc *et al.*, 1995; Cuc *et al.*, 1998).

Common name	Species	Taxonomic group	Part injured[1]
Citrus psyllid	*Diaphorina citri* Kuwayama	Homoptera: Psyllidae	S, L
Citrus leafminer	*Phyllocnistis citrella* Stainton	Lepidoptera: Gracillariidae	L
Citrus stinkbug	*Rhynchocoris humeralis* (Thnb.)	Heteroptera: Pentatomidae	F
Fruit-piercing moths	*Ophiusa coronata* (Fabricius) + *Eudocima* spp.	Lepidoptera: Noctuidae	F
Black citrus aphid	*Toxoptera aurantii* (Boyer de Fonscolombe)	Homoptera: Aphididae	S, L
Brown citrus aphid	*T. citricidus* (Kirkaldy)	Homoptera: Aphididae	S, L
Soft scales	Unidentified species (probably *Ceroplastes destructor* Newstead + others)	Homoptera: Coccidae	S, L, I, F
Hard scales	Unidentified species (probably *Parlatoria ziziphi* (Lucas) + *Chrysomphalus aonidum* (L.) + others)	Homoptera: Diaspididae	S, L, I, F
Citrus mealybugs	*Planococcus citri* (Risso) + unidentified species	Homoptera: Pseudococcidae	R, S, I, F
Inflorescence eaters	Unidentified	Lepidoptera: Pyralidae	I
Citrus red mite	*Panonychus citri* (Mc Gregor)	Acarina: Tetranychidae	L, F
Citrus rust mite	*Phyllocoptruta oleivora* Ashmead	Acarina: Eriophyidae	L, F
Greening (CGD)	*Liberobacter asiaticum*	Gram-negative bacterium	whole plant
Tristeza (CTV)	Citrus tristeza closterovirus	Closteroviridae	whole plant
Root rot	*Fusarium solani* Martius Sacc.	Hypocreales: Hypocreaceae	whole plant
Gummosis	*Phytophtora* sp.	Peronosporales: Pythiaceae	whole plant
Canker	*Xanthomonas campestris* pv. *citri* (Hasse) Dye	Bacteria	whole plant
Black spot	*Guignardia citricarpa* Kiely	Dothideales: Mycosphaerellaceae	L, F
Sooty mould	*Capnodium citri* Berk. & Desm.	Dothideales: Capnodiaceae	S, L, I, F
Scab	*Elsinoë fawcettii* Bitanc. et Jenkins	Dothideales: Elsinoaceae	L, F
Algal leaf spot	*Cephaleuros virescens* Künze	Chlorophyta: Trentepohliaceae	L

[1]R=roots, S=shoots, L=leaves, I=inflorescences, F=fruit.

Table 1.1.6.2. Major pest and disease problems in longan in the Mekong Delta (Source: Duc *et al.*, 1995; Cuc *et al.*, 1998).

Common name	Species	Taxonomic group	Part injured[1]
Longan fruit borers	*Conopomorpha* spp. +	Lepidoptera: Gracillariidae	S, L, F
	Conogethes punctiferalis (Guenée)	Lepidoptera: Pyralidae	S, L, I, F
Flower-feeding caterpillars	*Thalassodes* sp. + *Comibaena* sp.	Lepidoptera: Geometridae	I
Mealybugs	*Pseudococcus* spp.	Homoptera: Pseudococcidae	R, S, I, F
Longan stink bug	*Tessaratoma papillosa* (Drury)	Heteroptera: Pentatomidae	S, I, F
Fruit rot	*Phytophtora* sp. + unidentified species	Peronosporales: Pythiaceae	F

[1] R=roots, S=shoots, L=leaves, I=inflorescences, F=fruit.

The mango seed borer *Deanolis albizonalis* (Hampson) is the major insect pest in mango in the Mekong Delta (Table 1.1.6.3.). Oviposition takes place 45 to 55 days after flower initiation and continues up to fruit maturity (Waterhouse, 1998). Eggs are laid in groups of one to four on or near the peduncle at the base of the fruit. On hatching, three to four days later, larvae travel to the apex to enter the fruit. About two to three weeks later pupation occurs inside or outside the fruit. After 9 to 14 days adults emerge. The development from egg to adult takes 28 to 41 days. Adults live 8 to 9 days, are generally nocturnal and seldom attracted to light. In his overview on biological control of insect pests in SE Asia, Waterhouse (1998) did not mention this pest to occur in Vietnam and generally found very few references to the mango seed borer in the literature. He postulated that the damage due to the seed borer is commonly attributed to other causes. This might be the case, as in Vietnam, most mango farmers attributed this damage to the fruit fly *Bactrocera dorsalis* Hendel (Diptera: Tephritidae) (Chapter 8).

Several surveys on sapodilla have indicated that there are only few pests (Table 1.1.6.4.). The major pests are the fruit borer *Alophia* sp., the twig borer *Pachyteria equestris* Newman and the mealybug *Planococcus lilacinus* (Ckll.) (Cuc, unpublished data). No literature has been found on the life cycle of *Alophia* sp. At the Cantho University, preliminary laboratory experiments at 28 °C and field observations indicated that larvae hatch after three to four days, after which they enter the fruit. The five instars are completed in 13 to 17 days and pupation lasts 7 to 8 days. Adult longevity is 5 to 11 days. The borer attacks the very young fruit measuring *ca* 10 mm in diameter, and infestation continues until harvest. The damage can easily be observed by the insect frass and the drips of solidified white latex coming from the point where larvae have entered (the latex of sapodilla or *chicu* has originally been used by the Indians in South America, and is the predecessor of the current *chiclette* or chewing gum). Yield reduction by *Alophia* sp. has been estimated to be 30-60%. In other fruit crops, the pest and disease situation is more complex, and no estimates of fruit damage or yield loss have been made.

Table 1.1.6.3. Major pest and disease problems in mango in the Mekong Delta (Source: Duc *et al.*, 1995; Cuc *et al.*, 1998).

Common name	Species	Taxonomic group	Part injured[1]
Seed borer	*Deanolis albizonalis* (Hampson)	Lepidoptera: Pyralidae	F
Hoppers	*Idioscopus* spp.	Homoptera: Cicadellidae	S, L, I
Shoot borers	*Chlumetia transversa* (Walker) + unidentified species	Lepidoptera: Noctuidae	S, I
Anthracnose	*Colletotrichum gloeosporioides* (Penz.) Sacc.	Xylariales	S, L, I, F
Sooty mould	*Capnodium* sp.	Dothideales: Capnodiaceae	S, L, I, F
Frog skin spot	Unidentified		F

[1] R=roots, S=shoots, L=leaves, I=inflorescences, F=fruit.

Table 1.1.6.4. Major pest problems in sapodilla in the Mekong Delta (Source: Cuc, unpublished data).

Common name	Species	Taxonomic group	Part injured[1]
Fruit borer	*Alophia* sp.	Lepidoptera: Pyralidae	F
Mealybug	*Planococcus lilacinus* (Ckll.)	Homoptera: Pseudococcidae	R, S, I, F
Twig borer	*Pachyteria equestris* Newman	Coleoptera: Cerambycidae	T

[1] R=roots, S=shoots, T-twigs, L=leaves, I=inflorescences, F=fruit.

1.1.7. Pest control and biological control

In 1997-1998, from the nearly 500 fruit farmers interviewed, about 90% applied insecticides, 70% fungicides and about 20% herbicides. Generally about half of the fruit farmers used manual knapsack sprayers, the other half using motorised sprayers. As insecticide and fungicide spraying is often done overhead, the person who sprays the tree is highly exposed to pesticides. To spray tall trees such as mango and durian, the lance of the pesticide sprayer is connected to the tank by a long hose. One person climbs the trees to spray, while a second person stays on the ground and pumps the sprayer to provide the necessary pressure. Richer farmers with a relatively large orchard (> 1 ha), often hire labour to spray their trees. This labour is usually provided by farmers with small orchards (less than 0.3 ha), or by rice farmers during times that they are not occupied in their own paddy fields.

Farmers increasingly focusing on monocrop orchards such as Tieu mandarin, mango and longan has coincided with higher pesticide inputs (Van Mele and Hai, 1999), and long term sustainability should be questioned. From 1985 to 1993, annual chemical fertilizer use nearly doubled from 1.8 million tons to 3.3 million tons, of which more than 80% consisted of nitrogen fertillizers (DAFF, 1996). Problems with environmental conservation and sustainable agriculture have been addressed only recently in a two-day Workshop (January 19-20, 2000) organized by the Japanese International Co-operation Agency (JICA) in Can Tho. It was concluded that, despite the fact that the Vietnamese government has banned several highly toxic pesticides (see below), implementation of pesticide regulation needs to be enforced, and that research dealing with biological conservation in general, and biological control agents in particular, needs further support.

Recent surveys indicated that both in rice (Chiem *et al.*, 2000) and vegetables (Hai *et al.*, 2000) high amounts of the banned products methyl parathion, monocrotophos and methamidophos are still frequently applied. The organochlorine endosulfan with a high toxicity to fish, which is a major agricultural resource in the Mekong Delta, is still used by several farmers. Some vegetable and fruit samples taken from the market contained pesticide residues far exceeding the MRL (Cuc *et al.*, 2000; Hai *et al.*, 2000).

In the Deltas, in the perspective to grow fruit without residues and to conserve an environment without contaminating pesticides, the exploitation of endemic natural enemies should be further supported. In sapodilla, farmers traditionally use the black ant *Dolichoderus thoracicus* (Smith) (Hymenoptera: Formicidae) to control the fruit borer *Alophia* sp. (Lepidoptera: Pyralidae). This is especially common practice in Can Tho Province. In Tra Vinh Province, the area of sapodilla cultivation has strongly increased over the past years (personal observation). Although black ants are also often present in orchards, perceptions of the benefits are mixed, and consequently farmers use more pesticides than in Can Tho Province. Another ant species traditionally used as a biological agent, mainly by citrus farmers in the Mekong Delta and in the Northern Mountains and Midlands, is the weaver ant *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae) to control the citrus stinkbug

R. humeralis among other pests. In the Red River Delta, due to the high amounts of pesticides applied, on average 14 applications per year, the practice of weaver ant husbandry has completely disappeared (Pham Van Lam, pers. comm., 2000). Intensification of citrus production with biocontrol as an important component of integrated pest management should be well possible in Vietnam as it has been elsewhere, such as in Australia (Smith *et al.*, 1997), Europe (Vacante, 1995) and the United States (Flint, 1991).

1.2. Plant Protection in Vietnam

1.2.1. Plant Protection Department and Extension Service

In Vietnam, both the Plant Protection Department (PPD) and the Extension Service (ES) resort under the Ministry of Agriculture and Rural Development (MARD). There is one Head Office both for North and South Vietnam, and both PPD and ES have a parallel, hierarchical structure with offices and representatives in each province and district. The ES, however, was only established in 1993, whereas the PPD exists for much longer. In each province, the Service of Agriculture and Rural Development decides how the budget will be distributed between these two institutes, the Seed and Variety Development Centre and the Veterinary Department. This is based on the provincial priorities and an annual working plans submitted by each of these institutes. The hierarchical position at the provincial level is given in Figure 1.2.1.

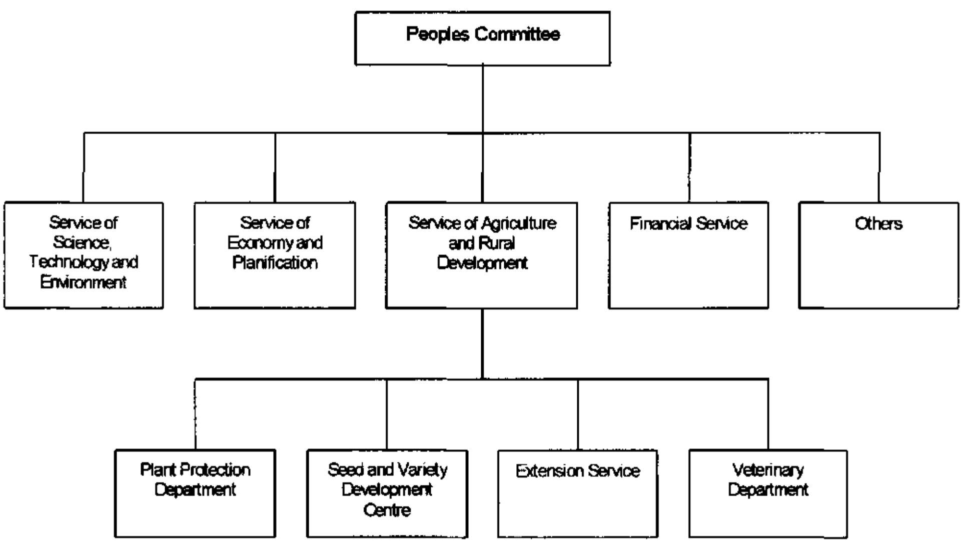

Figure 1.2.1. Position of the Plant Protection Department (PPD) and the Extension Service (ES) at the provincial level.

Traditionally, the PPD is responsible for pest surveillance, instruction of pest management practices and supply of pesticides (Chung and Dung, 1996). When the PPD was involved in IPM programmes in the early 1990s there appeared to be conflicting responibilities for pesticide supply and for reduction of pesticide use. In the mid-1990s MARD reorganized the PPD at the local level and shifted the pesticide supply function of the

PPD to the input supply companies, although in some locations the PPD was still selling pesticides (Chung and Dung, 1996). Especially since the PPD has been involved in the FAO National IPM Programme for rice since 1992 and for vegetables since 1996, their approach has been increasingly based on crop management and farmer participation. From 1993 onwards, pesticide shop keepers need to follow a training course organized by the PPD in order to get a license to sell chemical products.

The ES, on the other hand, deals with different aspects related to agriculture, including animal husbandry. Because this institute has been recently established, it is not yet equally strong developed in each province or district. Their methodology is mainly founded on the Transfer of Technology (TOT) and Training and Visit (T&V) principles. Region-wide, blanket recommendations are formulated and technology packages are transferred to farmers during field days, 1-3 days lasting courses or mass media campaigns. Depending on the financial status, the ES appoints and trains a varying number of extension co-ordinators at the village or community level. These co-ordinators meet with the technicians at the provincial level on a regular basis. The relationship between PPD and ES varies depending on the district or province.

1.2.2. Local organizations

Local organizations have also supported the development of the fruit sector. After the *Doi moi* policy reform in 1989, Farmers' Organizations (FO) were re-established and the most popular and efficient groups within this organization are the Farmers' Association, the Women Union and the Youth Group. The FO target small farmer groups such as the well-producing rice farmer groups, the experienced horticulture groups, the farmers' saving and credit groups, etc., and as such play an important role in the development of the community by strengthening and encouraging interactions between different individuals. The well-functioning of the FO, their impact and the type of groups targeted, is highly dependent upon regional initiatives and priorities. In a case study in Can Tho Province, Ni and Xuan (1998) indicated that a prerequisite for the sustainable development of a remote area, is the availability of qualified human resources. For the development of the growing fruit sector, scientific support and training of government staff and farmers have become increasingly important.

Each province has a Union of Associations of Science and Technology. In Can Tho Province, for instance, the Horticultural Association (HA) is but one of the 19 Associations belonging to this Union. The HA in Can Tho has currently about 6000 members, divided over several subgroups dealing with citrus, mango, sapodilla and durian. Its initial aim was to have a stronger position when lending money from the Bank to invest in the establishment of new orchards. As it is the village HA that lends money, individual farmers cannot loose their land authorization rights in case the loan is not paid back in time. This has already proven beneficial, especially for those farmers who had major problems with the citrus greening disease. Most HAs meet on an irregular basis to discuss and exchange information among its members. Meetings are co-ordinated by the Extension Service, who has close collaboration with these Associations.

1.2.3. National institutes supporting plant protection in fruit production

Over the past years more and more research institutes and universities conduct research on one or several aspects of fruit production as a direct consequence of its increasing economical importance. Some are concentrating their efforts on different aspects of integrated pest management, although chemical crop protection and testing of inorganic fertilizers still receives much emphasis.

At the National Institute of Plant Protection (NIPP), Hanoi, limited research has been initiated in co-operation with the German non-governmental organization (NGO), Bread for the World, on biological plant protection with botanical and microbial products against pests and diseases in orange, grapefruit, longan, litchi and durian. Since 1997, field studies at two different sites are conducted within the Vietnamese-Australian IPM in citrus project, which is funded by the Commonwealth Scientific and Industrial Research Organization (CSIRO), to evaluate the effect of petroleum spray oils (PSO) on citrus pests and natural enemies.

The Southern Fruit Research Institute (SOFRI) at Long Dinh, Tien Giang Province in the Mekong Delta, was only established in 1994. Scientists currently evaluate the effect of PSO in the framework of the same Australian project. They also work on the production of greening-free citrus seedlings in a collaborative project with the International Centre for Rural and Agricultural Development Research (CIRAD), France. Besides, the potential use of two parasitoids of the citrus psyllid *D. citri* is assessed. During the dry season, the two most promising parasitoids *Tamarixia radiata* (Hymenoptera: Eulophidae) and *Diaphorencyrtus aligarhensis* (Hymenoptera: Encyrtidae) had maximum parasitization rates of 57% and 32%, respectively (Duc and Tuyen, 1999). The parasitoids were able to develop throughout the year, but parasitization was reduced to less than 10% when broad-spectrum pesticides were used. The more selective and less toxic ethofenprox and PSO were more effective for psyllid control than the conventionally used broad-spectrum pesticides (Hai *et al.*, 1999).

Together with SOFRI, the Plant Protection Department of the Cantho University has a major task to train staff from ES and PPD, and also more recently to train fruit farmers. During one-day farmer workshops at District level, an open discussion with questions and answers follows the session at which the latest scientific findings are exposed. Staff from ES and PPD are trained during one-day to one-week lasting training courses. Most on-farm experiments are conducted in collaboration with the ES. Based on these experiments, technological packages are delivered through mass media campaigns. Topics cover specific problems such as diseases in mango and citrus or mite problems in citrus. These agricultural TV programmes are annually broadcasted at the beginning of the flowering or fruiting period of each crop.

1.2.4. Pesticide policy

World-wide, IPM approaches have succeeded in reducing the use of broad-spectrum pesticides. IPM methods have proven to be more economical than conventional ones using only chemicals (Heong *et al.*, 1995; Peng *et al.*, 1995; Papacek and Smith, 1998). In a lot of countries, the focus has shifted from pest control to pest management and from yield maximization to yield stability. Documenting the successes obtained in integrated pest management on one hand and stating the pesticide problems encountered at the international scene on the other hand, will create greater awareness at the policy level in order to shift support for agrochemical technologies to biologically-based technologies.

In the late 1980s, according to the FAO International Code of Conduct on Distribution and Use of Pesticides, most Asian countries lacked pesticide regulations on import, sales and use to ensure the safe and correct use of pesticides. In the late 1990s, most Asian countries, with the exception of Thailand, have adopted IPM as the official policy (Oudejans, 1999). In Vietnam, FAO has given strategic support to the government since 1992 dealing with four major topics, namely (1) pesticides and health, (2) pesticides and environment, (3) gender, and (4) pesticide policy. Pesticide policies can be assigned to three groups: regulatory policies, pricing policies and government investments (Waibel, 1993).

Despite successes of the FAO IPM programme in SE Asia, total pesticide sales steadily increased from 1980 to 1996 in most countries (Oudejans, 1999). Shares of sales for rice production in the total pesticide market dropped, especially in Indonesia, but were countered by increased pesticide sales for horticulture. As could be expected, over the same period the pesticide industry has increasingly focused its attention on the vegetable and fruit market. Especially in Thailand and Malaysia, sales for use in fruit crops showed an overall growth. From the mid-1980s onwards, the fruit sector in Thailand accounted for a stable

36% share of the total pesticide market (Oudejans, 1999). In 1993, *ca* 21% and 18% of the total insecticide and fungicide sales was for use in citrus (Jungbluth, 1995). This illustrates that the Thai government's policy of diversification from rice to crops with a high added value is well adopted by the agricultural sector.

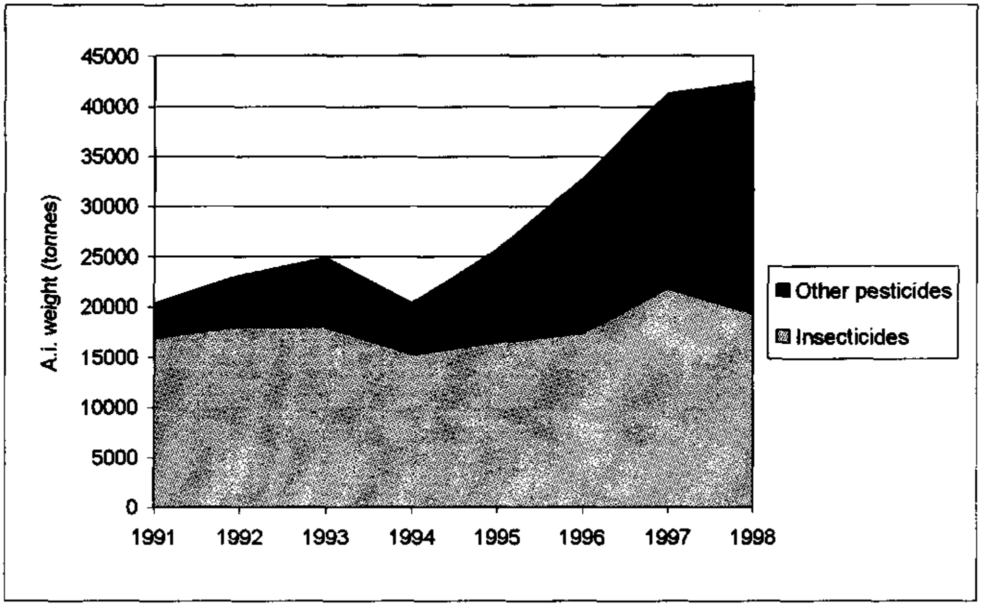

Figure 1.2.4.a. Quantity of active ingredients of pesticides imported in Vietnam between 1991 and 1998. The group 'other pesticides' comprise mainly of fungicides and herbicides. Source: Ministry of Agriculture and Rural Development, Vietnam, 1999.

For Vietnam, no information is available on pesticide sales for use in different crops. Vietnam's agricultural diversification policy only started in the late 1980s, after which many farmers converted their ricefields into fruit orchards. After 1988, similar as before the *Doi moi* policy reform, input imports still have to be done by the state export-import agency, and foreign exchange allocations are still highly controlled by the state (Pingali and Xuan, 1992). Data on the quantity of pesticides imported have only been recorded, or published, from 1991 onwards, the time that the Vietnamese government made a start with pesticide regulations.

Insecticide use remained rather stable over the period 1991-1998 (Figure 1.2.4.a.). The market share of other groups of pesticides increased rapidly from 1994 onwards, accounting for more than 50% of the total pesticide market in 1998. Only since 1994, more detailed data are available on the composition of the group 'other pesticides', comprising mainly of fungicides and herbicides.

The increase of fungicide sales only started from 1994 onwards. By that time the orchards established in the early 1990s became productive. Most farmers then opted for high value cash crops such as Tieu mandarin and longan, both with very high levels of fungicide use. In 1998, Tieu mandarin farmers targeted root rot on average 3 times per year (range 1-6), citrus canker 7 times per year (range 1-30) and citrus greening disease 5 times per year (range 2-18). Longan farmers sprayed fungicides mainly against fruit rot, on average 10 times per year (range 1-30). Besides, many longan farmers reported to spray fungicides because it gives the peel a whiter appearance, increasing its market value.

As the government also promoted crop intensification in rice, together with an improvement of the irrigation system in the Mekong Delta, this has resulted in a general shift from single to double and triple cropping and from transplanting to direct-seeding (Kon, 1998). This has created more weed problems and is most probably responsible for the increased sales of herbicides.

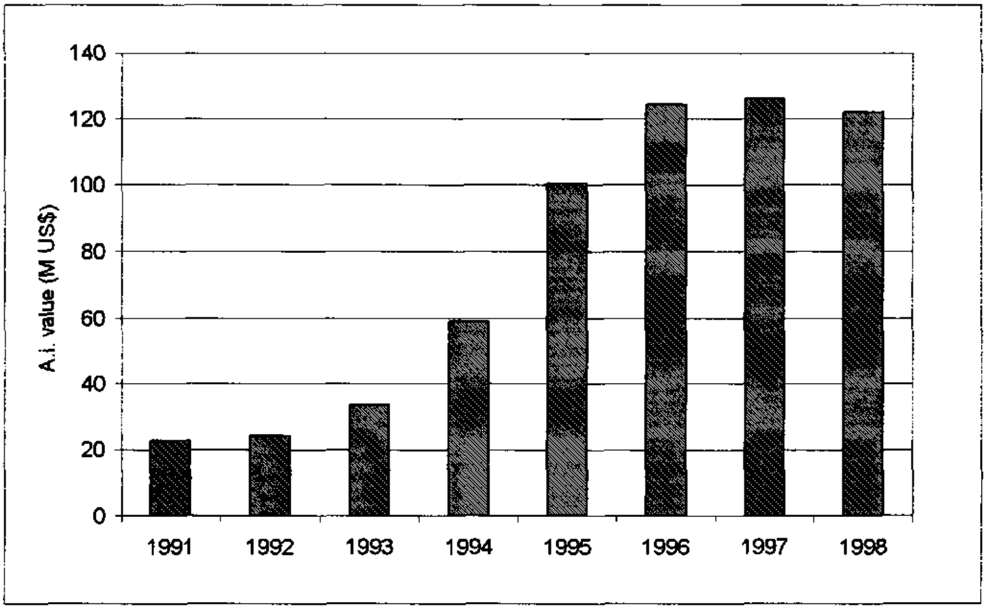

Figure 1.2.4.b. Value (M US$) of active ingredients of pesticides imported in Vietnam between 1991 and 1998. Source: Ministry of Agriculture and Rural Development, Vietnam, 1999.

Between 1991 and 1998, the value of active ingredients of pesticides imported in Vietnam has increased by 600% (Figure 1.2.4.b.). Besides the increased import from fungicides and herbicides, both rice farmers (Heong *et al.*, 1998) and fruit farmers (Van Mele and Hai, 1999; Chapter 4) have increasingly used insecticides, in particular pyrethroids. This occurred at the expense of the cheaper organophosphate methyl parathion, which was banned for use in agriculture in 1994 (box 1.2.4.). In 1999, a total of 26 active ingredients (a.i.) were banned for use in Vietnam.

Box 1.2.4.

Pesticide policy development in Vietnam

1991 The Ministry of Agriculture and Food Industry (MAFI) releases the first list of pesticides permitted for use in Vietnam. The list includes 77 active ingredients.

1992 MAFI releases a list on which 20 a.i. are banned and 14 a.i. restricted.

1993 The Executive Committee of the National Assembly issues a Decree of Plant Protection and Quarantine. The Government releases Decree No. 92CP on the management of pesticides.

1994 The Ministry of Agriculture and Rural Development (MARD) bans four pesticides for use in agriculture, namely methyl parathion, lindane, captan and captafol; and bans five pesticides for use in rice, namely methamidophos, monocrotophos, carbofuran, endosulfan and phosphamidon.

1995 The Government releases Decree No. 86CP on the authorized organization for management of quality of import/export commodities including pesticides. In this Decree, the quality of pesticides is under control of MARD.

1996 MARD bans the use of methyl parathion.

1997 MARD bans the import of methamidophos, monocrotophos and carbofuran.

1998 MARD bans the use of methamidophos, monocrotophos and phosphamidon in agriculture. PPD advises pesticide companies in Vietnam that the Department will no longer consider leaffolder control in rice as justification for registration. In November 1998, PPD stops registering insecticides for leaffolder control.

1999 MARD releases a list of pesticides including:

- 249 a.i. under 697 trade names that can be used;
- 26 a.i. under 36 trade names are restricted;
- 26 a.i. are banned.

One of Vietnam's problems in implementing an IPM oriented pesticide policy, is that MARD is responsible for pesticide control, while the taxes are under the responsibility of the Ministry of Finance. Both Ministries have different objectives and interests. Most of the pesticides available on the market belong to World Health Organization (WHO) toxicity class I and II (Anonymous, 1999). Due to the high competition, prices for these products are low. More selective pesticides, on the other hand, are only sold by one or two companies and prices are high. A team of economists from the Vietnam National University calculated that pesticide misuse in rice resulted in about 7 US$ on health costs per farmer and per rice crop, and that a tax level of about 33% should be imposed on current pesticide prices (Dung and Dung, 1999). MARD has proposed that taxes should be paid according to the toxicity level of the product, but this has so far been rejected by the Ministry of Finance. Pesticide use can be banned by MARD, but in case farmers ask pesticide sellers for these highly toxic products, companies seemingly can still opt to provide them or not.

1.2.5. IPM for rice

In recent years, a lot of work on IPM research and implementation has been done in SE Asia. Regional efforts have mainly concentrated on rice and vegetable production. Since 1989, multilateral aid has been allocated to Vietnam through the 'FAO Intercountry Program for Integrated Pest Control in Rice'. A national-wide IPM training-of-trainers and training-of-farmers campaign has been organized in rice in close collaboration with the PPD from 1992 onwards (Anonymous, 1997). Training is based on farmer field schools (FFS), which focus on four main principles: (1) grow a healthy crop, (2) make regular observations in the field, (3) conserve natural enemies, and (4) farmers become experts (van de Fliert, 1993; Matteson *et al.*, 1994; Waage, 1998). At present, in the whole country each district has at least two rice IPM trainers. By the end of 1998, over 9,616 FAO-funded and 5,740 locally funded FFS trained a total of 407,322 rice farmers, reaching over 5% of the farm households. About 1,000 IPM clubs with a membership of 52,798 farmers had been established country-wide. The structure and organization of IPM clubs vary with locality (FAO, 2000).

The International Rice Research Institute (IRRI) in the Philippines has also been collaborating with the PPD and several research institutes in the Mekong Delta of Vietnam. IRRI has established a regional-wide IPM Network for rice since 1992. Activities undertaken within this Network has covered farmers' spray patterns as well as farmers' knowledge and perception of rice pests (Heong and Escalada, 1997b). One of their conclusions was that many farmers unnecessary spray insecticides to control leaffolders during the first month of crop establishment (Heong *et al.*, 1994; de Kraker, 1996). Through farmer participatory experiments and mass media campaigns a reduction in insecticide use was obtained

(Heong and Escalada, 1997a; Heong and Escalada, 1998). Since 1999, research results led Vietnam to withdraw insecticide registration for leaffolder control.

1.2.6. IPM for vegetables

Since the mid 1990s, the European Community has been funding a project called 'Urban and peri-urban small and medium-sized enterprise development for sustainable vegetable production and marketing systems' in Vietnam, Laos and Thailand. In 1995, FAO initiated the 'Inter-Country Programme for the Development and Application of Integrated Pest Management in Vegetable Growing in South and SE Asia'. The countries involved are Bangladesh, Indonesia, Thailand, Laos, the Philippines and Vietnam. Now, in Vietnam, each province has at least two vegetable IPM trainers. In 2000, the Danish International Development Agency (DANIDA) has started a bilateral project on IPM in vegetables in three different provinces, partly in collaboration with the PPD. A pilot project has been set-up on training methodology through the ES in Can Tho Province.

Local initiatives have also been developed as acute pesticide poisonings frequently occurred due to ingestion of sprayed vegetables (VNS, 1996; VNS, 1998). Several provinces are spending a relatively large part of their budget to support 'clean vegetable' activities (Kim, pers. comm., 1999). Most of the farmers in Vietnam are aware of IPM in annual crops through local, national and/or international programmes. Due to media attention paid to pesticide poisonings, consumer awareness about 'clean vegetables' is also increasing.

1.2.7. IPM for tea

Since 1994, the international NGO Coopération Internationale pour le Développement et la Solidarité (CIDSE) has been developing an IPM programme for tea in Bac Thai Province, Northern Vietnam in collaboration with the PPSD (Plant Protection Department at the provincial level). The same approach was followed as that applied by FAO in rice. Initially, rice IPM facilitators from the PPSD were involved to organize farmer field schools (FFS) in which farmers learnt how to conduct agro-ecology analysis among other things. During these analyses it became obvious that farmers build on what they already knew about natural enemies, they mainly mentioned spiders and ladybeetles. The IPM facilitators were not really motivated to learn new things, namely how to deal with pests and natural enemies which are typical for tea. They lacked the initiative to start studying the tea ecosystem and preferred sticking to a previously set agenda (den Braber, pers. comm., 2000). Insufficient knowledge about the ecology and biology of the pest and natural enemy complex in tea blocked the dynamic process of reciprocal learning through field studies. In an evaluation report, Vuong *et al.* (1995) already mentioned that there is a general lack of information in Vietnam, and especially that of information which is based on local conditions. They suggested that the PPSD could further benefit from farmers' experience in developing technical recommendations.

1.2.8. The Vietnamese-Belgian 'IPM in Fruit Production' Project

As stated above, research on IPM in SE Asia has until now mainly focused on rice and vegetables. As pesticides in fruit and vegetable production constitute the second biggest part in the Asian crop protection market, it can only be hoped for that from now on, more and more emphasis will be put on IPM in fruit crops.

In Malaysia, research has mainly been limited to fruit fly control in starfruit (Vijaysegaran and Ibrahim, 1991). Collaborative efforts on citrus were made in the late eighties, early nineties by the United Nations Development Programme (UNDP) and FAO 'Intercountry Regional Project for the Control of Citrus Greening Disease', which yielded a lot of useful information on this particular topic (summarized in Chung and Shamsudin, 1991). During a workshop on IPM in the Asia-Pacific Region, fruit crops were given negligeable attention compared to other crops (Ooi *et al.*, 1992). In their book on production of economic fruits in SE Asia, Othman and Suranant (1995) described mainly chemical pest control and some cultural control practices. No information was presented on biological control or IPM. Only since 1989, a project 'IPM in Selected Fruit Trees' was co-financed by the Deutsche Geselschaft für Technische Zusammenarbeit (GTZ), Germany, and implemented by the Department of Agriculture (DOA) and the Department of Agricultural Extension (DOAE) of Thailand. The project has yielded much grey literature and manuals on IPM in durian (Distahaporn *et al.*, 1996), mango (DOA and DOAE, 1995) and tangerine (DOA and DOAE, 1996). However, the mango IPM manual still recommends the use of highly toxic pesticides. Seemingly, the Thai government has always lacked political interest in IPM programmes (Oudejans, 1999), and the GTZ-Project has only recently concentrated on policy reform, regulatory and supportive measures for the environmentally sound use of pesticides (Van Mele, 1998).

With the increasing importance of fruit production in Vietnam and as public awareness about environmental issues and human health grew, the development of an IPM fruit programme became increasingly necessary. In 1996, the Vietnamese-Belgian 'IPM in Fruit Production' Project was agreed upon as a project of the Vlaamse Interuniversitaire Raad (VLIR) between the Cantho University (CTU) in Vietnam and the Catholic University

Leuven (KU Leuven) in Belgium. In its initial phase, farmer problems were defined through on-farm surveys, key informant interviews and participant observation. These information retrieval methods were partly based on Norton (1993), Daxl *et al.* (1994), Schwab (1995) and Escalada and Heong (1997). Agronomic practices, socio-economic aspects, pest management and indigenous knowledge were given special emphasis. Fruit trees covered were citrus, durian, mango and longan.

Network building and co-operation with agricultural services, farmers associations, research institutes and universities has received high priority. Farmer meetings and annual symposia on 'Fruit Production in the Mekong Delta' have been organized to interchange information among all stakeholders. Based on results of these on-farm surveys and discussions at different fora and with different stakeholders, research priorities have been set.

1.3. IPM concepts in a historical context

Many different definitions of IPM have been developed over the last 30 years, and nearly everybody working in agriculture has his or her opinion about what the acronym stands for. The interpretation given to IPM differs in essence depending on the various sectors of the agricultural community and on the time factor (Morse and Buhler, 1997). This can be illustrated by the history of IPM in which there have been three levels of integration: (1) combining control methods and reducing pesticide applications; (2) integrating control methods in the farming system; and (3) developing IPM with the participation of farmers (van Huis and Meerman, 1997).

1.3.1. Combining control methods and reducing pesticide applications

The development of organic pesticides after the Second World War boosted agriculture to new heights. It was a common believe that insect problems could be solved permanently. With large-scale and indiscriminate use of synthetic insecticides, environmental problems associated with the use of these chemicals were almost inevitable to occur. The negative side-effects of pesticide use and the crucial role of naturally occurring predators, parasitoids and entomopathogens soon became apparent; risks for environment and human health were brought to the wider attention of the public by the book *Silent Spring* (Carson, 1962). Both at the international and national level, the thrive to maximize crop production increased further in the 1970s after the introduction of Green Revolution technology. Technologies were exclusively dependant on high input of agro-chemicals (Oudejans, 1999). This was perceived as a major cause for the occurrence of pest resistance, resurgence of secondary pests, environmental pollution and human health problems.

These concerns, among others, have driven the 'evolution' of insecticides and insecticide use. One of the predominant trends was the development of more selective insecticides and use of thresholds. The concept of economic thresholds was included by FAO in the definition of Integrated Pest Control (IPC): 'A pest management system that in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible, and maintains the pest population at levels below those causing economic injury' (FAO, 1966). The economic threshold was considered the central concept associated with adaptive/responsive pest management (Mumford and Norton, 1987) and fundamental to the practice of IPM.

However, for most farmers in developing countries economic threshold levels have little or no significance. Results of farm surveys in SE Asia have shown that farmers are highly risk averse and seem to use pesticides with little economic rationale. Pesticides are primarily used for prevention or for cure (Heong *et al.*, 1994; Burleigh *et al.*, 1998). Besides, most of the insecticides used in SE Asia are not selective and classified by the World Health Organization as extremely or highly toxic to humans (Heong and Escalada, 1997b; Van Mele, 1998; Oudejans, 1999; Van Mele and Hai, 1999). Although developing countries account for little of the total amount of pesticides used every year, they have the highest rates of pesticide poisoning in humans (Adams, 1990 and Beaumont, 1993 in Morse and Buhler, 1997). Poor labelling and lack of farmer education are some of the reasons. Over the years, it has become clear that for IPM to be successful, a different approach has to be developed with increased farmer involvement.

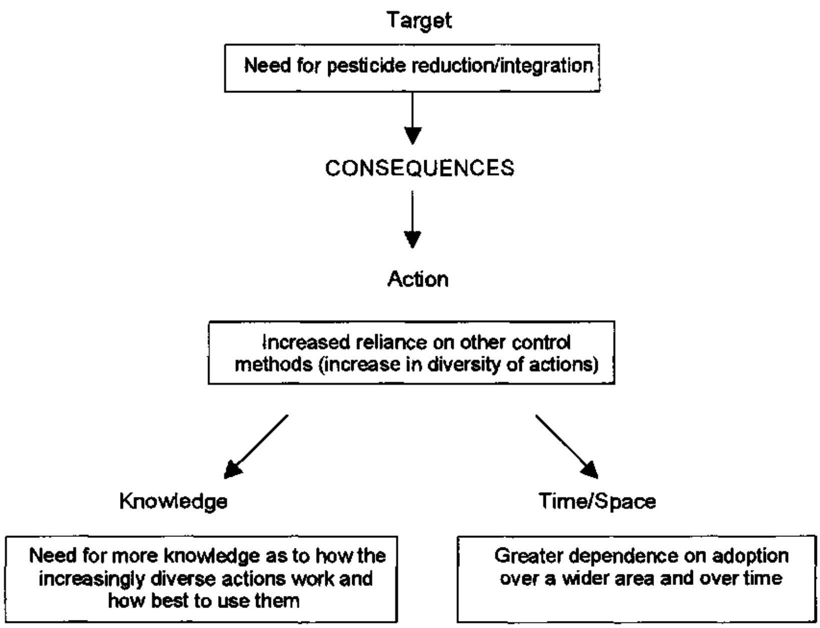

Figure 1.3.1. Some consequences of reduced pesticide use and integration with other crop protection technologies (Morse and Buhler, 1997).

Reduced use of pesticides implies that farmers increasingly need to rely on other non-chemical crop protection measures (Figure 1.3.1.). An increase in complexity or diversity of control methods requires knowledge. Besides, if only one farmer reduces pesticide application, natural enemies probably do not become sufficiently established due to pesticide applications in neighbouring farms. Therefore, the system dimension has to be increased from individual fields to regions with a similar cropping pattern, especially when conservation of natural enemies is strived for (Morse and Buhler, 1997).

The broader concept than IPC, namely that of Integrated Farming Systems (IFS) was re-introduced with the aim to substitute expensive and potentially polluting inputs, particularly fertilizers and pesticides, by non-chemical cultivation techniques and other IPM methods through increased agricultural and ecological knowledge (Teng and Savary, 1992). One of the main principles of IFS is to conserve and enhance the fauna and flora in and around the field in order to stabilize the agro-ecosystem as a preventive measure against outbreaks of pests, diseases and weeds (Vereyken, 1989). This will be further discussed in the next section.

1.3.2. Integration of control methods into the farming system

A farming system, as defined by Brush and Turner (1987), is any level of unit(s) engaged in agricultural production as it is wedded in a social, political, economic and environmental context, whereas a farming systems approach describes the unit(s) in its context and/or explores some characteristics of the unit(s) in terms of all or parts of the context. Other definitions tend to be more focused on the farmer and his community with the basic unit being the agro-ecosystem (Altieri *et al.*, 1983; Litsinger, 1993). The objectives of the study determine the choice of system boundaries (Rossing and Heong, 1996), but probably the most important contribution of system analysis is that pest problems are considered in a more holistic way (Heong, 1985; Teng, 1987; Vos, 1998).

Prokopy (1994) measured progress towards achieving IPM as analogous to climbing a step ladder, each step representing a different level of integration (Figure 1.3.2.a.). The fourth and top step envisions blending the concerns of all those having a vital interest in pest management: farmers, researchers, extension staff, consumers, processors and distributors, industry, government regulatory agencies.

The Integrated Pest Management Working Group of the Consultative Group for International Agricultural Research (CGIAR) stated in their synthesis report on IPM in developing countries that IPM demands greater skills of farmers in their being able to select from a choice of options which will be appropriate to their farming system at the time the decision has to be taken. IPM must be seen as a subset of crop management, itself a subset of farmer livelihood. Farmers manage complex cropping systems and experience has shown that they are capable of understanding the principles that must be applied to achieve IPM. The technologies themselves must be presented in a form that enables the farmer to see how they may be fitted into his or her farming system (NRI, 1991). This farming system research (FSR) concept assumes that the results of research can be successfully implemented when the technology developed is appropriate for the target farming system (van Huis and Meerman, 1997).

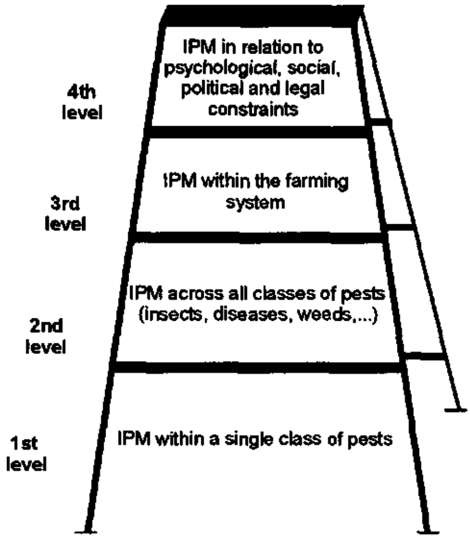

Figure 1.3.2.a. Four levels of integration in pest management. Progressing from one level to the next is viewed analogous to climbing a step ladder (after Prokopy, 1994).

IPM, however, does not always necessarily imply that new technologies have to be developed. Many of the non-insecticide crop protection methods have been developed by the farmers themselves and are an integral part of their crop husbandry technology (Litsinger, 1993). To integrate control methods into the cropping system, traditional pest management practices have been studied and results used as inputs for developing IPM packages (van Huis *et al.*, 1982; Atteh, 1984; Bentley, 1992; Trutmann *et al.*, 1996; Ochou *et al.*, 1998). Small modifications of existing plant protection practices have been suggested to be most easily adapted by farmers (Matteson *et al.*, 1984). For developing countries, most of the studies dealing with indigenous technical knowledge in pest management have covered cotton, vegetables and subsistence crops, but have been non-existent for tropical fruit crops. Describing traditional pest management practices of fruit farmers in the Mekong Delta, Vietnam, is one of the aims of this work. Throughout the next sections, special emphasis will be given to the use of ants as biological control agents.

The concept of biological pest control means the use of living natural enemies to control pest species. This can be accomplished either through (1) importation of exotic enemies against either exotic or native pests (*i.e.* classical biological control), or (2) conservation and augmentation of enemies that are already in place or are readily available in nature (Ehler, 1998). Conservation and augmentation could be considered as two points on a continuum. At one extreme is conservation in the form of pesticide selectivity or selective use of pesticides, and on the other extreme is augmentation through inoculative or inundative releases. Many environmental modifications are designed to both preserve and enhance natural enemies and thus lie at an intermediate point on this continuum. Conservation biological control or habitat management means the provision of resources, such as food and shelter, to natural enemies to improve their effectiveness at controlling pests (van Lenteren, 1987; Bugg and Picket, 1998). Habitat manipulation therefore seeks to manage the relationships between pest arthropods, natural enemies, crop and non-crop plants, and their physical environment. An obvious first step to support and sustain biological control is to encourage greater appreciation of field ecological research (Ooi, 1999).

Habitat manipulation has increasingly been recognized as an important condition to improve biological control with both exotic and indigenous natural enemies (Altieri and Whitcomb, 1979; Altieri, 1983; Andow, 1991; Liang and Huang, 1994; Barbosa, 1998; Gurr *et al.*, 1998; Pickett and Bugg, 1998; Altieri and Nicholls, 1999). One of the advantages is that farmers can manage the implementation of conservation biological control with minimal inputs of energy and labour. The earliest example of conservation biological control is from about AD 300 from the Canton area, China, where people collected nests of the weaver ant *O. smaragdina* and sold them to farmers who placed these nests in citrus trees to combat pests. Farmers then made bamboo strips that served as bridges for the ants moving from tree to tree (Olkowski and Zhang, 1998). The same authors stressed the importance of deliberate incorporation of generalist predators into farmers' pest management programmes. Greathead (1991) also emphasized the importance for the tropics to enhance the effectiveness of indigenous natural enemies, as opportunities for classical biological control in the tropics are limited and often depend on international institutional support.

Conserving indigenous natural enemies is seriously threatened by the loss and degradation of natural habitats. The application of agro-ecology principles as such embraces conservation biological control (Letourneau, 1998). Agro-ecology has in practical terms translated into programmes emphasizing recovering and re-evaluating farmers' knowledge and technologies, as well as sustainable natural resource management with reduced external chemical inputs (Thurston, 1992; Altieri, 1993). Some of the strategies to promote sustainable agriculture are the conservation of weeds in terms of soil improvement and of use potential (Chacon and Gliessman, 1982; Altieri, 1993; Van Mele and Phen, 1999), or to enhance biological pest control through well-planned diversification of the cropping system. Diversification can also take place outside the farm, in crop-field boundaries or at the landscape level. Letourneau (1998) clearly illustrated that the aims and objectives in conservation biology are, to some extent, comparable to those in conservation biological control. Living fences can improve habitat for wildlife and natural enemies. They provide flowers which are important in the adult nutrition of beneficial insects and for pollination, provide both wood and non-wood products for the farmers community, increase soil organic matter, etc. (van Emden and Williams, 1974; Altieri and Letourneau, 1982; Letourneau, 1998; Van Mele, 1999).

Several cultural management practices are worthwhile considering as important components of habitat manipulation (Figure 1.3.2.b.). Several of these practices have been presented in some of the next chapters, as has been indicated in the Figure.

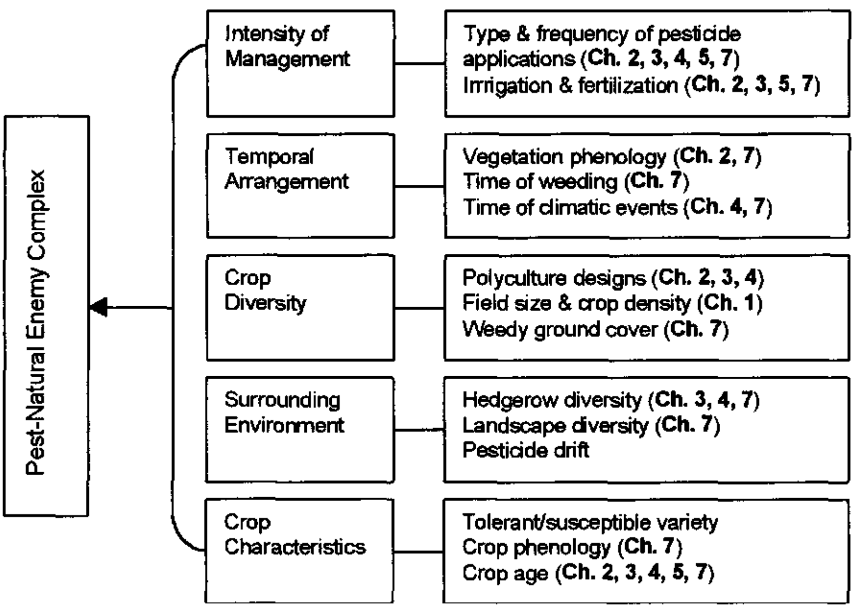

Figure 1.3.2.b. Some cultural management practices known to affect the dynamics of the pest-natural enemy complex (adapted from Altieri, 1994).

1.3.3. Developing IPM with farmers' participation

The FSR approach has four essential elements: (1) farmer first and last; (2) systems perspective; (3) interdisciplinary team formation; and (4) problem solving process to generate technology which flows from farmer to researcher/extensionist and back (Brush and Turner, 1987). A major doctrine in the FSR method is that agricultural technology is a product of the society that developed or invented it (Saint and Coward, 1977). However, in reality many of the FSR projects have not succeeded in effectively using and strengthening local knowledge systems. FSR continues to be a top-down approach: technologies continue to be developed in the Western knowledge system (Chambers and Jiggins, 1987; Thrupp, 1989; den Biggelaar, 1991) and consequently hamper IPM implementation in developing countries. For IPM to be successful in the tropics, a new approach had to be developed.

As IPM technology has to be location-specific due to high interactions between technology and the agro-ecosystem, fixed prescriptions have proven to be unworkable. As a consequence, farmer participatory research (FPR) has been promoted to increase involvement of farmers in technology design, development, diffusion and evaluation (Matteson, 1992; Altieri, 1993; ter Weel and van der Wulp, 1999; van Schoubroeck, 1999). Building on farmers' knowledge, and changing agricultural research, extension policy, and institutions has received increasing attention (Röling and van de Fliert, 1994; Scoones and Thompson, 1994; Matteson, 1996).

To illustrate how farmers in the Mekong Delta have been involved in information exchange in our Project, an example is given in box 1.3.3.

Box 1.3.3.

Farmer participation during a durian workshop in Ngu Hiep village

In Ngu Hiep village, Cai Lay District, Tien Giang Province, we initiated a workshop for farmers cultivating durian. This is a crop with a rather negligible economical impact at the national level, but durian cultivation is a main economic activity of many farmers in this region of the Mekong Delta. In 1995, it was cultivated on 1,900 ha (DAFF, 1996). Durian farmers had never been involved in any kind of group activities. During this workshop, co-organized by the regional People's Committee, 78 people participated of which 70 farmers, and 8 district and provincial technicians.

On request of the farmers, the workshop started by us giving a brief overview of results from the durian survey, which we conducted during the previous season. It enabled farmers, many of whom had participated in the survey, to see how their major production problems were often very common ones.

Secondly, a slide show was presented on IPM in durian, as observed in Thailand during an evaluation mission (Van Mele, 1998). Slides illustrating pest problems and management techniques practised by Thai farmers were combined with slides taken in orchards from participating Vietnamese farmers. This invoked lively reactions among farmers. They wanted to know how Thai farmers tackled problems similar to theirs, especially *Phytophtora* root rot.

During the third part of the workshop, the floor was given to four farmers to present some of their innovative techniques. These farmers had been identified during our survey, and were asked one month in advance to give a presentation during the workshop. Initially, farmers were quite restricted in sharing their knowledge, but the continuous flow of questions posed by their colleagues made them reveal more of their 'secrets' than they probably had initially planned. Getting farmers on the floor and giving a short talk through a microphone was no problem, as every Vietnamese person is used to sing at home, in restaurants or with friends in karaoke bars. Besides, they are proud being asked to present something for a group. Once on the floor, however, it was the interaction with the audience that 'made the show go on'. It was a good example of how farmers can become highly motivated to share their knowledge when they are given the floor.

After the workshop, several farmers volunteered to co-operate in IPM experiments in their own orchard.

1.4. Farmers' knowledge, perceptions and practices (KPP)

1.4.1. Definitions of farmers' knowledge

Farmers' knowledge for the scope of this work will be defined as 'the body of knowledge which farmers developed through interaction between indigenous and scientific knowledge and which continuously adapts to changes in environmental, socio-cultural and politico-economic conditions'.

Indigenous knowledge or local knowledge as described by Thrupp (1989), is restricted to 'insights and adaptive skills of farmers often derived from many years of experience and which have co-evolved with the local environment'. Farmers' knowledge is therefore a broader term which incorporates indigenous knowledge. As both sources of knowledge are dynamic and evolve continuously, it is sometimes difficult to make a clear distinction between the two. When developing an IPM programme, one should not be restricted to studying indigenous knowledge, but try to consider the whole set of variables influencing farmers' current state of knowledge.

1.4.2. Importance of farmers' KPP

Evaluating farmers' knowledge, perceptions and practices in pest management is especially useful to set research agendas, identify gaps between farmers' knowledge and scientists' knowledge, for planning campaign strategies and developing messages for communication. Mainly due to the widespread outbreak of the rice brown planthopper *Nilaparvata lugens* Ståhl, farmers' perceptions and practices received increased attention and was evaluated in a broader socio-economical, political context (Kenmore *et al.*, 1987). It has been illustrated that a large proportion of insecticide sprays administered by farmers in Asia is influenced by misperceptions and overestimations of damage (Kenmore, 1987; Tait and Napompeth, 1987; Mai *et al.*, 1993; Heong *et al.*, 1995; de Kraker, 1996; Heong and Escalada, 1997b; Mai *et al.*, 1997; Tjornhom *et al.*, 1997). Most rice farmers apply their first sprays during the first 40 days after crop establishment to control leaf-feeding insects. However, these pests do not occur in sufficiently high numbers to cause yield loss. Besides, these early sprays may contribute to outbreaks of secondary pests such as the brown planthopper.

Over the past ten years, intensified focus on knowledge, perception and practices in rice pest management combined with basic research has led to the development of several successful extension strategies (Escalada and Heong, 1993; Adesina *et al.*, 1994; Adhikarya, 1994; Heong and Escalda, 1997a). After farmers tested a simple rule-of-thumb in pest management that was in conflict with their prevailing perceptions, many of them reduced their number of insecticide sprays. This change in perception and practice was possible mainly because of dissonance resolution, reduced costs and labour reduction. Most other studies documenting farmers' KPP in pest management, however, have mainly remained anecdotic such as those for cotton (Ochou *et al.*, 1998), vegetables (Medina, 1987; Pollard, 1991; Trutmann *et al.*, 1993, 1996) and subsistence crops (Atteh, 1984; Conelly, 1987; Chitere and Omolo, 1993; Bottenberg, 1995; Youm and Baidu-Forson, 1995). No information is available on whether these studies have actually contributed to the development of IPM technology or methodology.

Similar reports on perennial crops are even more limited (Nathaniels, 1998), and are nearly non-existent for tropical fruit crops. The beneficial role of natural enemies such as the weaver ant *Oecophylla smaragdina* has been scientifically illustrated for cashew in Australia (Peng *et al.*, 1995). Some attention has been given to farmers' knowledge related to weaver ant husbandry in citrus in China (Huang and Yang, 1987) and Vietnam (Barzman *et al.*, 1996; Van Mele and Cuc, 1999). However, none of these papers address farmers' perception of pests and their pesticide use patterns, which in many cases in developing countries is a major component of pest management (Heong and Escalada, 1997b; Burleigh *et al.*, 1998). Besides, most of the studies covering farmers' KPP lack the broader socio-economical, political context in which farmers' KPP exists.

1.4.3. Building on farmers' KPP reduces cost of IPM programmes

It is often thought that the implementation of IPM requires large inputs of financial and human resources. This is a generalized misconception, as in many situations farmers using simple IPM methods, or just by refraining from the use of pesticides, can keep pests below acceptable levels. Many NGOs working on sustainable rural development have often successfully integrated IPM in their programmes (Altieri, 1993). In the late 1970s, scientists at the International Potato Center (CIP) in Peru compared the financial inputs and success of the mainstream technology focused FSR approach with farmer participatory methods (Fujisaka, 1992). Over 80% of the budget was used by FSR and less than 20% when participatory methods were used. Besides, the latter method resulted in a potato storage technique that was successfully diffused among the farmers' community.

Another misconception is that IPM would only be possible with an accurate knowledge of the agro-ecosystem and the parameters that govern it. This idea was still defended in 1991 by the IPM Working Group of the CGIAR as they stated that 'Progress can only be made through exhaustive, and often wearisome, research. This is expensive and demanding on skilled manpower' (NRI, 1991). This conception has a clear and strong bias towards scientific knowledge systems. Scientists, being developers of the IPM concept, have too often stressed the scientific knowledge intensive nature of IPM, so as to increase fund raising for their own research (Morse and Buhler, 1997). Although the development of an IPM programme is greatly handicapped by the lack of basic data on the biology and ecology of the pest and its interactions with other environmental factors, it does not mean that an IPM programme cannot be implemented. Evidently, the practice of IPM need not wait until all the characteristics of a pest problem have been gathered, analyzed and completely understood. IPM should preferentially be based on the biological and ecological knowledge available and developed in close co-operation with farmers and other stakeholders such as extension staff, plant protection staff and government officials.

One of the goals of the CGIAR is to sustainably improve agriculture for instance through resource conservation and management (Khan, 1998). However, resources should not only been seen as biological or physical entities, but should equally include the (re)source of human knowledge. In the context of biological control, knowledge is itself a product (Waage, 1999). In those crops without a long history of research and development (R&D), availability of basic data is important to direct IPM R&D programmes, rather than IPM systems *per se* (Dent, 1995). IPM is a dynamic learning process and success often depends on whether all the different stakeholders are sufficiently motivated to co-operate in R&D. In Bhutan, success in controlling the citrus fruit fly *Bactrocera minax* could be obtained within a period of a few years only by developing a socio-technical IPM package, rather than a technological package (van Schoubroeck, 1999).

In Queensland, Australia, IPM in citrus has evolved over the past 20 years and is now being practiced by the majority of the farmers (Papacek and Smith, 1998). It was not necessary to convince farmers that they should adopt IPM. Initial suspicion was followed by interest, and eventually IPM was widespread adopted and farmers committed to its cause. Research has played a very important role by tackling the key problems first, providing a platform for early on-farm trials which eventually lead to IPM. Farmers' perceptions of pests and pest damage have been continuously used as a feedback for the IPM programme. What makes Vietnam comparable to Australia is that both countries have a strong and ongoing commitment to practical research trying to solve day to day problems. However, for research in pest management it should be borne in mind that both pests and natural enemies are considered. Otherwise the chance is big that the research agenda will be very much pesticide oriented and that both researchers, policy makers and farmers will be trapped in the pesticide treadmill.

1.4.4. Different classes of farmers' knowledge and perception

Farmers generally know a lot about some conspicuous and culturally important aspects of the local agro-ecosystem, while they lack knowledge of other aspects. A farmers' knowledge and perception classification framework was developed by Bentley (1992) based on ease of observation and importance. The characteristics of these classes are illustrated in Figure 1.4.4.

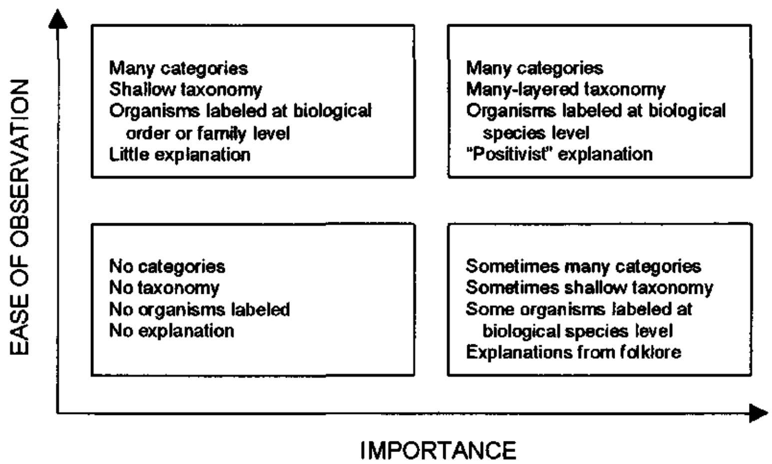

Figure 1.4.4. Characteristics of four classes of farmers' knowledge and perception (after Bentley, 1992).

1.4.5. Symbiosis between different knowledge systems

Basic research is essential to answer questions concerning the exploitation of IPM practices for best long-term results. Research building on farmers' practice has most chance of being implemented by farmers (Matteson *et al.*, 1984; Fujisaka, 1990, 1991; Escalada and Heong, 1993; Bottrell, 1996). If sustainable agriculture is taken seriously, the decentralized 'bottum-up' approaches must be complemented by a strong 'top-down' commitment (Röling, 1994; Matteson, 1996; van Schoubroeck, 1999). This necessitates strong institutional support for the development of IPM, stressing long-term planning both at the national and international policy level.

Symbiosis implies a form of interaction with mutual benefits for both parties. Synthesizing indigenous and scientific knowledge systems can indeed be beneficial for both farmers and scientists. Bentley (1989) wrote a paper on 'What farmers don't know can't help them'. Evidently, the same can be said for scientists, extension staff and policy makers. As a result of this mutual interest, many authors have stated that the ultimate solution for sustainable agriculture can be achieved by synthesizing scientific and indigenous or farmers' knowledge (den Biggelaar, 1991; Pimbert, 1991; Altieri, 1993; Morse and Buhler, 1997; Debrah *et al.*, 1998). Learning gaps in farmers' knowledge is an important step in the dynamic process of developing IPM (Figure 1.4.5.).

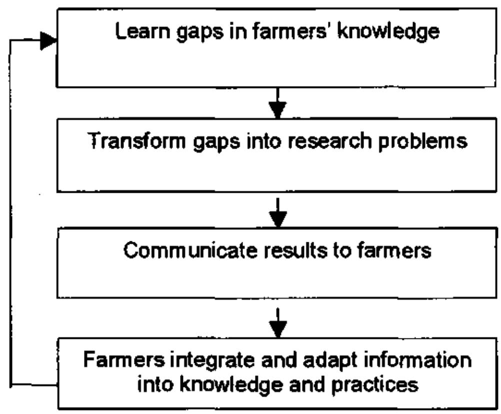

Figure 1.4.5. A proposed radical change in the research sequence. (Adapted from Bentley and Andrews, 1996, in Heong and Escalada, 1997b).

Bentley (1989, 1991) illustrated that Honduran farmers have extensive knowledge of the names of weeds in and around their field, while they lack appreciation for beneficial organisms and over-react to certain leaf-damaging insects. Because farmers tend to view all insects as their enemies they like to use pesticides. In rice, scientific research illustrated that rice plants can compensate for leaf loss at the early stages of crop establishment without affecting the yield. However, farmers' misperception of potential yield loss attributed to leaf-feeding insects has often lead to pesticide misuse (Heong *et al.*, 1994; Heong and Escalada, 1997b). Farmers and scientists may differ in their interpretation of the importance of a pest. What observers see when they view an object or event is not solely determined by the images on their retinas, but depends also on their experience, knowledge, expectations and inner states (Cashman, 1991). Farmers, after acquiring basic scientific knowledge or insights about specific agro-ecosystem principles, can make farm management decisions more accurately and independently and often become the best experts in their field. Areas where skills were still weak after training rice farmers in the Philippines included natural enemy identification, fungal disease identification, and control methods for virus diseases (Kenmore, 1987).

Besides of illustrated differences between farmers' and scientific knowledge, the type, extent and distribution of farmers' knowledge also varies a lot between and within farmer communities. Studying farmers' knowledge could therefore help indicating which farmers could be integrated in the development of knowledge transfer activities. Differences in farmer-to-farmer knowledge transfer depend on whether or not this knowledge is used for personal interests. Individual knowledge that is used for aims of market competition tends to be kept more confidential than knowledge that is needed for mutual interests (Thrupp, 1989). This might partly explain why fruit farmers in the Mekong Delta generally exchange little information among each other (see box 1.3.3). Because farmers live in an environment that contains many competing sources of information, it is necessary for research to address how these different sources influence farmers' KPP (Heong and Escalada, 1997b). One of the aims of this work is to study farmers' knowledge, and to put it in a socio-cultural and politico-economic context to highlight merits and constraints of incorporating this knowledge in development programmes.

1.4.6. Factors contributing to eroding indigenous knowledge

As traditional farming systems are prone to many external forces, it is important to assess current indigenous knowledge before it is too late (Farrington, 1988; Morse and Buhler, 1997). Eroding indigenous knowledge is often the case where (i) the importance of the cash economy becomes so great that farmers seek to maximize yield, and (ii) where population growth has exceeded the rate at which indigenous knowledge can enhance the carrying capacity of land (Farrington, 1988). Both of these factors are strongly acting in Vietnam.

Since the *Doi moi* policy reform in Vietnam in 1986, privatization of land and other production factors has lead to conversion from paddy fields and mixed orchards to monocrop orchards, as well as an increased presence and importance of agrochemical companies. Despite the relatively long non-productive period of fruit crops after orchard establishment, present-day fruit farmers seem to be highly responsive to market prices, changing from one fruit species to another if one year the price is low or yields are poor (Le Coq *et al.*, 1997). Tieu mandarin farmers aim at elevated yields of spotless fruit through high chemical inputs. Also sweet orange farmers increasingly seem to depend on pesticides. Direct consequences of the agricultural policy have been increased pesticide use and reduced biodiversity, threatening the traditional use of endemic ant species as successful biological control agents.

1.4.7. Legitimising indigenous knowledge

As many different factors interact on the marginalization of indigenous knowledge, different ways to legitimize and develop indigenous knowledge have to be taken into consideration. To restore confidence and dynamism in these knowledge systems, external intervention may be necessary. Scientific validation by local and foreign scientists may increase farmers' pride in the use of traditional knowledge (Thrupp, 1989).

Changing farmers' practices to more sustainable practices requires a learning process, as sustainable agriculture is information-intensive instead of physical input-intensive (Röling and van de Fliert, 1994). This learning process is enhanced through farmer participation and empowerment. The T&V system of linear technology transfer from researcher-to-extensionist-to-farmer should be replaced or at least be complemented to mobilize farmers' creativity and participation in technology development and exchange (Ashby, 1990). Participatory approaches can also enhance solidarity between farmers having common interests and increase potential economic and political bargaining power, as has been the case with Western fruit farmers applying integrated crop management techniques. Empowerment of people can also be stimulated when they are given the chance to demonstrate the validity of their knowledge to other farmers, through farmer-to-farmer extension projects and group workshops.

According to Farrington (1988) it is important for scientists to build upon components of indigenous knowledge, which are not inconsistent with scientific knowledge. Bentley (1992) goes one step further and proposes different approaches of collaboration between scientists and farmers based on the classification framework of farmer knowledge (Figure 1.4.4.). As rural people have extensive knowledge about relatively conspicuous organisms that are of perceived cultural importance, this is where scientists can learn most from them. One of the topics he describes as being an important source of indigenous knowledge, is the use of 'non-weeds' and the behaviour of large social insects such as honey bees. Honduran farmers did not perceive ant predation as important since they did not know that some insects could eat other insects, whereas ant-stinging behaviour was perceived as important. When farmers found out that ants help control pests, the idea of predation did become important.

An important issue for building upon indigenous knowledge has been synthesized by Bentley *et al.* (1994) as 'find out what people know and explain what they don't know in a way that is compatible with what they know'. Existing concepts should be used as much as possible to explain certain aspects of the agro-ecosystem.

1.5. Objectives and outline of thesis

In the Mekong Delta, Vietnam, it is common knowledge that ants have always played an important role in different fruit production systems, including mango, citrus and sapodilla. However, so far the government has given little attention to scientifically or technically support these traditional production systems. With an ever increasing presence of the agro-industry, government officials and newcoming fruit farmers have become persuaded that the use of chemicals is a prerequisite to improving production. The general objectives of the thesis are:

- (i) to define factors which influence farmers' knowledge, perceptions and practices (KPP) in pest management;
- (ii) to illustrate farmers' KPP in conservation biological control using ants.

The ultimate aim of this study was to gain insights in farmers' KPP and their dynamics, in order to contribute to the development of more relevant research and extension programmes. Although the majority of the studies presented here can be classified as deductive science, at which inferences are made from a set of observations rather than testing hypotheses by rigorous experiments, several hypotheses *sensu lato* have been formulated:

- (i.1) cropping practices may influence farmers' perception of pests and natural enemies and vice versa;
- (i.2) extension activities have a positive impact on farmers' KPP in pest management;
- (i.3) older farmers prefer to stick to traditional fruit production practices;
- (i.4) farmers' KPP is irrespective of the production region;
- (i.5) current government's policy is detrimental for traditional and future activities in biological control;
- (ii.1) biological control with ants is ecological, but not economical justifiable;
- (ii.2) fruit farmers who know about natural enemies have a different perception of pests and consequently use less chemicals;
- (ii.3) mixed orchards are *per se* better than orchards under monocrops;
- (ii.4) ants in orchards automatically increase the abundance of honeydew-producing insects;

In Table 1.5. the thesis outline is schematically given in relation with the hypotheses covered and methods used.

Table 1.5. Outline of the thesis in relation to the hypotheses and indicating the different methods used to evaluate farmers' KPP.

Ch.	Hypotheses	Methods					
		Grey literature evaluation	Key informant interview	Farmer interview	Participatory farmer observation	Field observation	On-farm experiment
2	i.1; i.2	X	X	X			
3	i.1; i.2; i.4; ii.2; ii.3; ii.4	X	X	X	X	X	X
4	i.1; i.5; ii.1; ii.2; ii.3	X	X	X	X	X	
5	i.1; i.3; ii.2; ii.4	X		X			
6	i.2; i.4; i.5	X	X	X			
7	i.1; ii.3	X	X	X	X	X	

In Chapter 1, an overview has been given of the importance of fruit production in Vietnam, both in a socio-economic and historical context. Local, national and international efforts supporting (integrated) plant protection have been included to give a state-of-the-art of the 'IPM athmosphere' in the country. Special attention has been paid to the Vietnamese government's agricultural policy in general, and the pesticide policy in particular. The development and implementation of IPM is strongly enhanced if it can build on farmers' KPP and if habitat manipulation to enhance biological control is taken into consideration. In Figure 1.3.2.b. the different chapters touching on conservation biological control have been indicated.

In Chapter 2, mango farmers' KPP in pest management is presented as a first case study. About 10 years ago, farmers hardly used any pesticides in this crop and the weaver ant *O. smaragdina* readily occurred. Because of this recent drastic chance in pest management practices this crop gives a good insight in how vulnerable traditional practices can be. As chemical pest control has become common practice, pest recognition and pest monitoring should receive more attention. Because other cultural techniques like pruning or trimming, however, have not co-evolved this has become a serious constraint for practicing integrated pest management.

The increasing presence of the agro-business has not had similar impacts on all fruit cropping systems. As opposed to mango, which is a high value crop, the market value of sapodilla is much lower, and therefore traditional practices of biological control have so far not disappeared. Biological control with the endemic ant species *D. thoracicus* in this crop has been discussed in Chapter 3. Sapodilla farmers' perception of the benefits and disadvantages of this ant has helped prioritizing research activities. During multi-location on-farm experiments, the infestation by the fruit borer *Alophia* sp. (Lepidoptera: Pyralidae) and the mealybug *Planococcus lilacinus* (Cockerell) (Homoptera: Pseudococcidae) has been followed throughout the fruiting stage. Results have been evaluated in relation to differences in habitat and irrigation techniques.

The next four chapters deal with citrus farmers, because this crop has a high potential economic importance in Vietnam. Although weaver ant husbandry has traditionally been practiced in South China and throughout Vietnam's citrus producing areas, today in Vietnam this practice can nearly only be found in the Mekong Delta. Farmers' traditional knowledge about *O. smaragdina* has been valued through farmer surveys, key informant interviews and on-farm observations (Chapter 4) and conferred in relation to socio-economic conditions, cropping pattern and evolution of pesticide use.

As pesticide use was much lower by farmers practicing weaver ant husbandry, it has been evaluated whether farmers assess incidence and severity of individual pest problems and attributed yield loss differently when weaver ant populations are high (Chapter 5). Measured as a percentage of the total number of target sprays, the relative importance of each citrus insect pest could be compared in function of the cropping system and ant abundance.

Because it became obvious that not only the presence of ants influenced farmers' pest perceptions and management practices, but also the different pesticide information sources, in Chapter 6 we have investigated the interactions between the major sources of information and the type of pest problems recorded by farmers, the type of pesticides applied and the frequency of spraying.

In one of the previous chapters two pest species, namely the citrus leafminer *Phyllocnistis citrella* Stainton (Gracillariidae: Lepidoptera) and the citrus red mite *Panonychus citri* (Mc Gregor) (Tetranychidae: Acarina) were identified as receiving most target sprays, irrespective of the presence of ants. Clearly other alternatives to tackle these pest problems had to be investigated. Therefore, in Chapter 7 we have discussed citrus farmers' KPP related to both these pests, and farmers' weed management practices, as well as the importance of habitat manipulation in the larger context of the mixed orchard-ricefield landscape of the Mekong Delta. Evaluating phenological aspects of major non-crop plant species has enabled us to map pollen and nectar availability over space and time. Possible improvements of current weed management practices in the development of more sustainable pest management have been presented.

In Chapter 8 the results have been summarized and discussed in a broader context. Recommendations and potential bottlenecks for developing IPM fruit programmes have been presented.

References

Adesina, A. A., Johnson, D. E. and Heinrichs, E. A. 1994. Rice pests in the Ivory Coast, West Africa: farmers' perceptions and management strategies. International Journal of Pest Management, 40, 293-299.

Adhikarya, R. 1994. Strategic Extension Campaign: a participatory-oriented method of agricultural extension. FAO, Rome, 209 pp.

Altieri, M. A. 1993. Designing and improving pest management systems for subsistence farmers. In: M. A. Altieri (ed.) Crop Protection Strategies for Subsistence Farmers. Westview Press, Boulder, Colorado, pp. 1-44.

Altieri, M. A 1994. Biodiversity and Pest Management in Agroecosystems. The Haworth Press, New York, pp. 185.

Altieri, M. A. and Letourneau, D. K. 1982. Vegetation management and biological control in agroecosystems. Crop Protection, 1, 405-430.

Altieri, M. A. and Nicholls, C. I. 1999. Biodiversity, Ecosystem Function, and Insect Pest Management in Agricultural Systems. In: W. W. Collins and C. O. Qualset (eds) Biodiversity in Agroecosystems. CRC Press, Boca Raton, pp. 69-84.

Altieri, M. A. and Whitcomb, W. H. 1979. The potential use of weeds in the manipulation of beneficial insects. Hortscience, 14, 12-18.

Altieri, M. A., Letourneau, D. K. and Davis, J. R. 1983. Developing sustainable agroecosystems. Bioscience, 33, 45-49.

Andow, D. A. 1991. Vegetational diversity and arthropod population response. Annual Review of Entomology, 36, 561-586.

Anonymous 1997. National IPM meeting. FAO Intercountry Program, Hanoi, 27-28 March 1997. MARD, Hanoi, Vietnam, 27 pp.

Anonymous 1999. Database on pesticides and the environment. Economic and Social Commission for Asia and the Pacific (ESCAP), Centre de co-opération Internationale en Recherche Agronomique pour le Développement (CIRAD), Commission of the European Union (EU). http://www.fadinap.com/pesticide.

Ashby, J. A. 1990. Small farmers' participation in the design of technologies. In: M. A. Altieri and S. B. Hecht (eds) Agroecology and Small Farm Development. CRC Press, Boca Raton, pp. 245-253.

Atteh, O. D. 1984. Nigerian farmers' perception of pests and pesticides. Insect Science and Its Application, 5, 213-220.

Aubert, B. 1990. Prospects for citriculture in Southeast Asia by the year 2000. FAO Plant Protection Bulletin, 38, 151-173.

Barbosa, P. 1998. Agroecosystems and conservation biological control. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 39-54.

Barbosa, P. 1998. Conservation Biological Control. Academic Press, London, pp. 396.

Barzman, M. S., Mills, N. J. and Cuc, N. T. T. 1996. Traditional knowledge and rationale for weaver ant husbandry in the Mekong Delta of Vietnam. Agriculture and Human Values, 13(4), 2-9.

Bentley, J. W. 1989. What farmers don't know can't help them: the strenghts and weaknesses of indigenous technical knowledge in Honduras. Agriculture and Human Values, 6(3), 25-31.

Bentley, J. W. 1992. The epistemology of plant protection: Honduran campesino knowledge of pests and natural enemies. In: R. W. Gibson and A. Sweetmore (eds) Proceedings of a Seminar on Crop Protection for Resource-Poor Farmers. CTA/NRI, pp. 107-118.

Bentley, J. W. and Andrews, K. L. 1996. Through the road blocks: IPM and Central American smallholders. Gatekeeper Series No. 56. International Institute for Environment and Development, London.

Bentley, J. W., Rodriguez, G. and Gonzalez, A. 1994. Science and people: Honduran campesinos and natural pest control inventions. Agriculture and Human Values, 11, 178-182.

Berkes, F., Folke, C. and Gadgil, M. 1995. Traditional ecological knowledge, biodiversity, resilience and sustainability. In: C. A. Perrings, K. G. Maeler, C. Folke, C. S. Holling and B. O. Jansson (eds) Biodiversity Conservation, Problems and Policies. Kluwer Academic Publishers, Dordrecht, pp. 281-299.

Bottenberg, H. 1995. Farmers' perceptions of crop pests and pest control practices in rainfed cowpea cropping systems in Kano, Nigeria. International Journal of Pest Management, 41, 195-200.

Bottrell, D. G. 1996. The research challenge for integrated pest management in developing countries: a perspective for rice in Southeast Asia. Journal of Agricultural Entomology, 13, 185-193.

Brush, S. B. and Turner II, B. L. 1987. The nature of farming systems and views of their change. In: B. L. Turner II and S. B. Brush (eds) Comparative Farming Systems. The Guilford Press, New York, pp. 11-48.

Bugg, R. L. and Picket, C. H. 1998. Introduction: enhancing biological control – habitat management to promote natural enemies of agricultural pests. In: Pickett, C. H. and Bugg, R. L. (eds) Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, California, pp. 1-23.

Burleigh, J. R., Vingnanakulasingham, V., Lalith, W. R. B. and Gonapinuwala, S. 1998. Pattern of pesticide use and pesticide efficacy among chilli growers in the dry zone of NE Sri Lanka (System B): perception vs reality. Agriculture, Ecosystems & Environment, 70, 49-60.

CABI 1998. Crop Protection Compendium – CDRom Module 1. CAB International, Wallingford, U.K.

Cao-Van, P., Bourdeaut, J. and Chau, N. M. 1997. Les culture fruitières au Vietnam, examples des agrumes et du litchi dans la diversification agricole. Agriculture et Développement, 15, 119-125.

Carson, R. 1962. Silent Spring. Houghton Mifflin, Boston, USA, 368 pp.

Cashman, K. 1991. Systems of knowledge as systems of domination: the limitations of established meaning. Agriculture and Human Values, 8(1/2), 49-58.

Chacon, J. C. and Gliessman, S. R. 1982. Use of the 'non-weed' concept in traditional tropical agroecosystems of southeastern Mexico. Agro-Ecosystems, 8, 1-11.

Chambers, R. and Jiggins, J. 1987. Agricultural research for resource-poor farmers. Part 1: transfer-of-technology and farming systems research. Agricultural Administration and Extension, 27, 35-52.

Chau, N. M. 1998. Evaluation of the potential of fruit trees in the Mekong Delta: prospect in domestic and export consumption. In: Commercialization of Tropical Fruits in South Vietnam. Workshop Proceedings Southern Fruit Research Institute, Long Dinh, June 12-13, 1998, pp. 54-65.

Chi, T. T. N., Khoa, N. T., Tam, B. T. T. and Paris, T. R. 1995. Gender roles in rice farming systems in the Mekong River Delta: an exploratory study. In: G. L. Denning and V. T. Xuan (eds) Vietnam and IRRI: A Partnership in Rice Research. Proceedings of a Conference held in Hanoi, Vietnam, May 4-7, 1994, pp. 291-299.

Chiem, N. H., Tuyen, T. Q., Bac, T. C. and Du, L. V. 2000. Impact of intensive cultivation of triple rice cropping on the agro-ecological environment of the Mekong Delta. Paper presented at the First Joint Workshop on Environmental Conservation and Sustainable Agriculture, Cantho University, January 19-21, 2000. JICA-CTU Project for the improvement of environmental education in agricultural sciences. (in Vietnamese).

Chitere, P. O. and Omolo, B. A. 1993. Farmers' indigenous knowledge of crop pests and their damage in western Kenya. International Journal of Pest Management, 39, 126-132.

Chung, D. K. and Dung, K. T. 1996. Pest Management in Rice Production in Vietnam: a Socioeconomic Assessment. Hanoi Agricultural University, Hanoi, pp. 67.

Chung, K. E. and Shamsudin, B. O. 1991. Rehabilitation of Citrus Industry in the Asia Pacific Region. UNDP-FAO Regional Project, 213 pp.

Conelly, W. T. 1987. Perception and management of crop pests among subsistence farmers in south Nyanza, Kenya. In: J. Tait and B. Napompeth (eds) Management of Pests and Pesticides: Farmers Perception and Practices. Westview Press, Boulder, Colorado, pp. 198-209.

Cuc, N. T. T., Thu, N. T. X. and Tri, N. T. 2000. Residues of some insecticides in soil, water and fruits and effect of insecticides on the abundance of soil fauna in fruit orchards. Paper presented at the First Joint Workshop on Environmental Conservation and Sustainable Agriculture, Cantho University, January 19-21, 2000. JICA-CTU Project for the improvement of environmental education in agricultural sciences. (in Vietnamese).

Cuc, N. T. T., Hung, N. V. and Dien, L. Q. 1998. Insect pests on citrus, durian, longan and mango in selected provinces of the Mekong Delta of Vietnam. In: P. Van Mele and N. V. Huynh (eds) Proceedings of the First Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management. Cantho University, Can Tho, Vietnam, pp. 71-76. (in Vietnamese).

DAFF (Department of Agriculture, Forestry and Fishery) 1996. Statistical Data of Agriculture, Forestry and Fishery 1985-1995. Statistical Publishing House, Hanoi, 411 pp.

DAFF (Department of Agriculture, Forestry and Fishery) 1999. Statistical Data of Agriculture, Forestry and Fishery 1990-1998 and forecast in the year 2000. Statistical Publishing House, Hanoi.

Dang, N. P. 1997. Le rôle de la vulgarisation dans la promotion de la culture des arbres fruitiers dans le Delta du Mékong. Mémoire diplôme du Master VOPA. Centre National d'Études Agronomique des Régions Chaudes, Montpellier, pp. 114.

Daxl, R., von Kayserlingk, N., Klein-Koch, C., Link, R. and Waibel, H. 1994. Integrated pest management: guidelines. Schriftenreihe der GTZ, No. 249, 119 pp.

Debrah, S. K., Defoer, T. and Bengaly, M. 1998. Integrating farmers' knowledge, attitude and practices in the development of sustainable *Striga* control interventions in southern Mali. Netherlands Journal of Agricultural Science, 46, 65-75.

de Kraker, J. 1996. The potential of natural enemies to suppress rice leaffolder populations. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 257.

den Biggelaar, C. 1991. Farming systems development: synthesizing indigenous and scientific knowledge systems. Agriculture and Human Values, 8(1/2), 25-36.

Dent, D. R. 1995. Introduction. In: D. R. Dent (ed.) Integrated Pest Management. Chapman & Hall, London, pp. 1-7.

Disthaporn, S-A, Kraturuek, C. and Sutthiarrom, S. 1996. Manual for Integrated Pest Management in Durian. DOA-GTZ, Bangkok, Thailand, 101 pp.

DOA and DOAE (Department of Agriculture and Department of Agricultural Extension) 1995. Handbook on Mango Farm Care and Management Using Integrated Pest Management Methods. DOA-GTZ, Bangkok, Thailand, 68 pp.

DOA and DOAE (Department of Agriculture and Department of Agricultural Extension) 1996. Studying Manual on IPM in Tangerine. DOA-GTZ, Bangkok, Thailand, 43 pp.

Duc, H. T. and Tuyen, N. D. 1999. Population dynamics of the parasite complex on citrus psyllid *Diaphorina citri* at Tien Giang. In: P. Van Mele and N. V. Huynh (eds) Proceedings of the Second Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management. Cantho University, Can Tho, Vietnam, pp. 49-54. (in Vietnamese).

Duc, H. T., Lai.T. K, Thuy, N. N. and Tuyen, N. D. 1995. Preliminary Results on Pests and Diseases Investigation in the Mekong Delta. SOFRI research report to the Ministry of Agriculture and Food Industry, pp. 50-54. (in Vietnamese).

Dung, N. H. and Dung, T. T. T. 1999. Economic and health consequences of pesticide use in paddy production in the Mekong Delta, Vietnam. EEPSEA Research Report, Vietnam National University, Ho Chi Minh City.

Ehler, L. E. 1998. Conservation biological control: past, present and future. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 1-8.

Escalada, M. M. and Heong, K.L. 1993. Communication and implementation of change in crop protection. In: D. J. Chadwick and J. Marsh (eds) Crop Protection and Sustainable Agriculture. Wiley, Chisester, pp. 191-207.

Escalada, M. M. and Heong, K. L. 1997. Methods for research on farmers' knowledge, attitudes, and practices in pest management. In: K. L. Heong and M. M. Escalada (eds) Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, Philippines, pp. 1-34.

FAO 1966. Report of the FAO Symposium on Integrated Pest Control. Rome, Italy, October 1965.

FAO 2000. Community Integrated Pest Management. http://www.communityipm.org/vietnam.htm.

Farrington, J. 1988. The role of indigenous technical knowledge. In: J. Farrington and A. Martin (eds) Farmer Participation in Agricultural Research. Overseas Development Insitute, pp. 23-29.

FEER (Far Eastern Economic Review) 1999. Vol. 162(37), p. 28-29.

Fujisaka, S. 1990. Rainfed lowland rice: building research on farmer practice and technological knowledge. Agriculture, Ecosystems & Environment, 33, 57-74.

Fujisaka, S. 1991. What does 'build research on farmer practice' mean? Rice crop establishment (Beusani) in eastern India as an illustration. Agriculture and Human Values, 8, 93-98.

Fujisaka, S. 1992. Will farmer participatory research survive in the International Agricultural Research Centres? Gatekeeper Series No. SA44. International Institute for Environment and Development, London, pp. 3-14.

Greathead, D. J. 1985. The importance of taxonomy in biological control: identification and information services: insect orders of major importance. In: P. Ferrar and D.-H. Stechmann (eds) Biological Control in the South Pacific, pp. 105-119.
Greathead, D. J. 1991. Biological control in the tropics: present opportunities and future prospects. Insect Science and Application, 12, 3-8.
Gurr, G. M., van Emden, H. F. and Wratten, S. D. 1998. Habitat manipulation and natural enemy efficiency: implications for the control of pests. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 155-183.
Hai, T. V., Ba, T. T., Son, P. K., Hai, T. T., Nga, N. T. T., Dung, H. A. and Tri, T. V. 2000. Survey of cultivation practices, pesticide use and pest control in vegetables in Can Tho, Soc Trang and An Giang Province in 1998. Paper presented at the First Joint Workshop on Environmental Conservation and Sustainable Agriculture, Cantho University, January 19-21, 2000. JICA-CTU Project for the improvement of environmental education in agricultural sciences. (in Vietnamese).
Hai, T. V., Hai, T. T., Son, P. K., Dung, P. V. and Ann, A. 1999. Effect of some insecticides on citrus psyllid (*Diaphorina citri* Kuwayama) and its parasitoid wasps. In: P. Van Mele and N. V. Huynh (eds) Proceedings of the Second Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management. Cantho University, Can Tho, Vietnam, pp. 41-48. (in Vietnamese).
Heong, K. L. 1985. Systems Analysis in Solving Pest Management Problems. In: B. S. Lee, W. H. Loke and K. L. Heong (eds) Integrated Pest Management in Malaysia. MAPPS, Kuala Lumpur, pp. 133-149.
Heong, K. L. and Escalada, M. M. 1997a. Perception change in rice pest management: A case study of farmers' evaluation of conflict information. Journal of Applied Communication, 81, 3-17.
Heong, K. L. and Escalada, M. M. 1997b. Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, Philippines, 245 pp.
Heong, K. L. and Escalada, M. M. 1998. Changing rice farmers' pest management practices through participation in a small-scale experiment. International Journal of Pest Management, 44, 191-197.
Heong, K. L., Escalada, M. M. and Mai, V. 1994. An analysis of insecticide use in rice: Case studies in the Philippines and Vietnam. International Journal of Pest Management, 40, 173-178.
Heong, K. L., Teng, P. S. and Moody, K. 1995. Managing rice pests with less chemicals. Geojournal, 35, 337-349.
Heong, K. L., Escalada, M. M., Huan, H. and Mai, V. 1998. Use of Communication media in changing rice farmers' pest management in the Mekong Delta, Vietnam. Crop Protection, 17, 413-425.
Hong, L. T. T. 1998. Development of Vietnamese fruit comodity on the background of world fruit market situation. In: Commercialization of Tropical Fruits in South Vietnam. Workshop Proceedings Southern Fruit Research Institute, Long Dinh, June 12-13, 1998, pp. 84-89.
Huang, H. T. and Yang, P. 1987. The ancient cultured citrus ant. Bioscience, 37, 665-671.
Jungbluth, F. 1995. Economic factors of pesticide use in Thailand. In: Proceedings of the Semi-Annual Workshop Integrated Pest Management in Selected Fruit Trees, Bangkok, 12-14 June, 1995, pp. 9-24.
Kenmore, P. E. 1987. Crop loss assessment in a practical integrated pest control programme for tropical Asian rice. In: P. S. Teng (ed.) Crop Loss Assessment and Pest Management. APS Press, St. Paul, Minnesota, pp. 225-241.
Kenmore, P. E., Litsinger, J. A., Bandong, J. P., Santiago, A. C. and Salac, M. M. 1987. Philippine rice farmers and insecticides: thirty years of growing dependancy and new options for change. In: J. Tait and B. Napompeth (eds) Management of Pests

and Pesticides. Farmers' Perceptions and Practices. Westview Press, Boulder, Colorado, pp. 98-108.

Khan, Z. D. 1998. Integrated pest management and CGIAR system. RIS Biotechnology and Development Review, 2, 19-30.

Kon, T. 1998. Rice cropping in the Mekong Delta. In: V. T. Xuan and S. Matsui (eds) Development of farming systems in the Mekong Delta of Vietnam. Ho Chi Minh City Publishing House, Ho Chi Minh City, pp. 214-233.

Le Coq, J., Tuyen, N. Q., Huon, L., Ha, V. V. and Can, N. D. 1997. *Libéralisation* économique, intensification et diversification: étude d'une région agricole au cœur du Delta de Mékong. Agriculture et Développement, 15, 35-42.

Letourneau, D. K. 1998. Conservation biology: lessons for conserving natural enemies. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 9-38.

Levins, R. and Vandermeer, J. H. 1990. The agroecosystem embedded in a complex ecological community. In: C. R. Caroll, J. H. Vandermeer and P. M. Rosset (eds) Agroecology. McGraw-Hill, New York, pp. 341-362.

Liang, W. G. and Huang, M. D. 1994. Influence of citrus orchard ground cover plants on arthropod communities in China: a review. Agriculture, Ecosystems & Environment, 50, 29-37.

Lim, G. S. and Ooi, P. A. C. 1985. Integrated Pest Management Concept: Perception and Implementation in Malaysia. In: B. S. Lee, W. H. Loke and K. L. Heong (eds) Integrated Pest Management in Malaysia, MAPPS, Kuala Lumpur, pp. 19-35.

Litsinger, J. A. 1993. A farming systems approach to insect pest management for upland and lowland rice farmers in tropical Asia. In: M. A. Altieri (ed.) Crop Protection Strategies for Subsistence Farmers. Intermediate Technology Publications, London, pp. 45-101.

Luat, N. V. 1998. On the efficiency of commercial fruit production. In: Commercialization of Tropical Fruits in South Vietnam. Workshop Proceedings Southern Fruit Research Institute, Long Dinh, June 12-13, 1998, pp. 46-50.

Mai, V., Cuc, N. T. T. and Hung, N. Q. 1993. Farmers' perceptions of rice pest problems and management tactics used in Vietnam. International Rice Research News, 18, 31.

Mai, V., Huan, N. H., Heong, K. L., Escalada, M. M. and Lazaro, A. A. 1997. Rice farmers' pest management perceptions and practices in Long An province, Vietnam. In: K. L. Heong and M. M. Escalada (eds) Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, pp. 215-226.

Matteson, P. C. 1992. 'Farmer first' for establishing IPM. Bulletin of Entomological Research, 82, 293-296.

Matteson, P. C. 1996. Implementing IPM: policy and institutional revolution. Journal of Agricultural Entomology, 13, 173-183.

Matteson, P. C., Altieri, M. A. and Gagné, W. C. 1984. Modification of small farmer practices for better pest management. Annual Review of Entomology, 29, 383-402.

Matteson, P. C., Gallagher, K. D. and Kenmore, P. E. 1994. Extension of integrated pest management for planthoppers in Asian irrigated rice: empowering the user. In: R. F. Denno and T. J. Perfect (eds) Ecology and Management of Planthoppers. Chapman and Hall, London, pp. 656-685.

Medina, C. P. 1987. Pest control practices and pesticde perceptions of vegetable farmers in Loo Valley, Benguet, Philippines. In: J. Tait and B. Napompeth (eds) Management of Pests and Pesticides: Farmers Perception and Practices. Westview Press, Boulder, Colorado, pp. 150-157.

Morse, S. and Buhler, W. 1997. Integrated pest management: Ideals and Realities in Developing Countries. Lynne Riener Publishers, London, 171 pp.

Mumford, J. D. and Norton, G. A. 1987. Economics of integrated pest control. In: P. S. Teng (ed) Crop Loss Assessment and Pest Management. APS Press, St. Paul, Minnesota, pp. 191-200.

Nathaniels, N. 1998. Self help, cashew trees, and learning in rural primary schools, Nachingwea District, Tanzania. Workshop Proceedings IPM Communications and Information Workshop for Eastern and Southern Africa (ICWESA). International Centre for Insect Physiology and Ecology (ICIPE), Nairobi, Kenya, pp. 142-147.

Ni, D. V. and Xuan, V. T. 1998. Rural development in a remote area: a case study at Hoa An, Phung Hiep, Can Tho. In: V. T. Xuan and S. Matsui (eds) Development of Farming Systems in the Mekong Delta of Vietnam. Ho Chi Minh City Publishing House, Ho Chi Minh City, pp. 181-210.

Noda, T., Loc, N. T. and Du, P. V. 1998. Rice pest management in the Mekong Delta. In: V. T. Xuan and S. Matsui (eds) Development of Farming Systems in the Mekong Delta of Vietnam. Ho Chi Minh City Publishing House, Ho Chi Minh City, pp. 272-287.

Norton, G. A. 1993. Philosophy, Concepts and Techniques. In: G. A. Norton and J. D. Mumford (eds) Decision Tools for Pest Management. CAB International, Wallingford, pp. 1-21.

NRI 1991. A Synopsis of Integrated Pest Management in Developing Countries in the Tropics. Natural Resources Institute, Chatham, 20 pp.

Ochou, G. O., Matthews, G. A. and Mumford, J. D. 1998. Farmers' knowledge and perception of cotton insect pest problems in Cote d'Ivoire. International Journal of Pest Management, 44, 5-9.

Olkowski, W. and Zhang, A. 1998. Habitat management for biological control, examples from China. In: C. H. Pickett and R. L. Bugg (eds) Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, California, pp. 255-270.

Ooi, P. A. C. 1999. Ensuring successful implementation of biological control in the tropics. In: Loke and S. S. Soetikno (eds) Proceedings of the International Symposium on Biological Control in the Tropics. CAB International, Serdang, Malaysia, pp. 18-20.

Ooi, P. A. C., Lim, G. S., Ho, T. H., Manolo, P. L. and Waage, J. 1992. Integrated Pest Management in the Asia-Pacific Region. CAB International, Wallingford, pp. 459.

Othman, Y. and Suranant, S. 1995. The Production of Economic Fruits in South-East Asia. Oxford University Press, New York, 419 pp.

Oudejans, J. H. M. 1999. Studies on IPM policy in SE Asia. Two centuries of plant protection in Indonesia, Malaysia and Thailand. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 316.

Papacek, D. and Smith, D. 1998. Sustaining IPM as a commercial service to citrus growers. Sixth Australasian Applied Entomological Research Conference, Brisbane, Australia, 29th Sep-2nd Oct. 1998, Vol. 1, pp. 106-112.

Peng, R. K., Christian, K. and Gibb, K. 1995. The effect of the green ant *Oecophylla smaragdina* (Hymenoptera: Formicidae), on insect pests of cashew trees in Australia. Bulletin of Entomological Research, 85, 279-284.

Pickett, C. H. and Bugg, R. L. 1998. Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, California, 433 pp.

Pingali, P. L. and Xuan, V. T. 1992. Vietnam: decollectivization and rice productivity growth. In: A. M. Tang and J. S. Worley (eds) Economic Development and Cultural Change. The University of Chicago Press, Chicago, pp. 697-718.

Pimbert, M. P. 1991. Designing integrated pest management for sustainable and productive futures. Gatekeeper Series No. 29. IIED, London.

Poapongsakorn, N., Meenakanit, L., Waibel, H. and Jungbluth, F. (eds) Approaches to Pesticide Policy Reform – Building Consensus for Future Action. Pesticide Policy

Project Publication Series No. 7. Institute for Economics in Horticulture, Hannover, pp. 87.

Pollard, G. V. 1991. Constraints to IPM development and a strategy for management of tomato and cabbage pests in Trinidad, West Indies. Tropical Pest Management, 37, 59-62.

Prokopy, R. J. 1994. Integration in orchard pest and habitat management: a review. Agriculture, Ecosystems & Environment, 50, 1-10.

Ratanawaraha, C. 1999. Agricultural research for environmental conservation: new dimensions of plant protection. In: Poapongsakorn, N., Meenakanit, L., Waibel, H. and Jungbluth, F. (eds) Approaches to Pesticide Policy Reform – Building Consensus for Future Action. Pesticide Policy Project Publication Series No. 7. Institute for Economics in Horticulture, Hannover, pp. 52-62.

Röling, N. 1994. Facilitating sustainable agriculture: turning policy models upside down. In: I. Scoones and J. Thompson (eds) Beyond Farmer First – Rural People's Knowledge, Agricultural Research and Extension Practice. Intermediate Technology Publications, London, pp. 245-248.

Röling, N. and van de Fliert, E. 1994. Transforming extension for sustainable agriculture: the case of integrated pest management in rice in Indonesia. Agriculture and Human Values, 11, 96-108.

Rossing, W. A. H. and Heong, K. L. 1996. Opportunities for using systems approaches in pest management. Field Crops Research, 1038, 1-18.

Rothuis, A. J., Nhan, D. K., Richter, C. J. J. and Ollevier, F. 1998. Rice with fish culture in the semi-deep waters of the Mekong Delta, Vietnam: a socio-economic survey. Aquaculture Science, 29, 47-57.

Saint, W. S. and Coward, W. Jr. 1977. Agriculture and behavioral science: emerging orientations. Science, 197, 733-737.

Sahn, N. V., Xuan, V. T. and Phong, T. A. 1998. History and future of farming systems in the Mekong Delta. In: V. T. Xuan and S. Matsui (eds) Development of Farming Systems in the Mekong Delta of Vietnam. Ho Chi Minh City Publishing House, Ho Chi Minh City, pp. 16-80.

Schwab, A. 1995. Pesticides – aid to agriculture or poison – and the conflicting role of the development worker. In: R. Altenburger (ed.) Pesticides in Tropical Agriculture. Margraf Verlag, Weikersheim, pp. 107-147.

Scoones, I. and Thompson, J. (eds) 1994. Beyond Farmer First – Rural People's Knowledge, Agricultural Research and Extension Practice. Intermediate Technology Publications, London, pp. 301.

Sharma, M. C. 1998. Integrated pest management in developing countries. RIS Biotechnology and Development Review, 2, 9-18.

Singh, R. B. 1993. Fruit Production in the Asia-Pacific Region. In: R. B. Singh (ed.) Research and Development of Fruits in the Asia-Pacific Region. RAPA Publication 1993/9, Bangkok, Thailand, pp. 1-26.

Smith, D., Beattie, G. A. C. and Broadly, R. 1997. Citrus pests and their natural enemies. Integrated pest management in Australia. Queensland Dept. of Primary Industries, pp. 272.

Tait, J. and Napompeth, B. 1987. Management of Pests and Pesticides. Farmers' Perceptions and Practices. Westview Press, Boulder, Colorado, pp. 244.

Teng, P. S. 1987. The Systems Approach to Pest Management. In: P. S. Teng (ed.) Crop Loss Assessment and Pest Management. APS Press, St. Paul, Minnesota, pp. 160-167.

Teng, P. S. and Savary, S. 1992. Implementing the systems approach in pest management. Agricultural Systems, 40, 237-264.

ter Weel, P. and van der Wulp, H. 1999. Participatory Integrated Pest Management. Policy and Best Practice Document 3. Ministry of Foreign Affairs, the Hague, pp. 67.

Thrupp, L. A. 1989. Legitimizing local knowledge: from displacement to empowerment for third world people. Agriculture and Human Values, 6(3), 13-24.

Thurston, H. D. 1992. Sustainable Practices for Plant Disease Management in Traditional Farming Systems. Westview Press, Oxford, pp. 279.

Tjornhom, J. D., Norton, G. W., Heong, K. L., Talekar, N. S. and Gapud, V. P. 1997. Determinants of pesticide misuse in Philippine onion production. Philippine Entomologist, 11, 139-149.

Trutmann, P., Voss, J. and Fairhead, J. 1993. Management of common bean diseases by farmers in the Central African Highlands. International Journal of Pest Management, 39, 334-342.

Trutmann, P., Voss, J. and Fairhead, J. 1996. Local knowledge and farmer perceptions of bean diseases in the Central African Highlands. Agriculture and Human Values, 13, 64-70.

Vacante, V. 1995. Integrated Control in Citrus Fruit Crops. IOBC wprs Bulletin, 18(5), pp. 199.

van de Fliert, E. 1993. Integrated Pest Management: Farmer Field Schools Generate Sustainable Practices. A Case Study in Central Java Evaluating IPM Training. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 404.

van Emden, H. F. and Williams, G. F. 1974. Insect stability and diversity in agro-ecosystems. Annual Review of Entomology, 19, 455-475.

van Huis, A. and Meerman, F. 1997. Can we make IPM work for resource-poor farmers in sub-Saharan Africa? International Journal of Pest Management, 43, 313-320.

van Huis, A., Nauta, R. S. and Vulto, M. E. 1982. Traditional pest management in maize in Nicaragua: a survey. Mededelingen Landbouwhogeschool Wageningen, 82-6, 43 pp.

van Lenteren, J. C. 1987. Environmental manipulation advantageous to natural enemies of pests. In: Delucchi, V. (ed.) Integrated Pest Management: Quo Vadis? Parasitis 86, Geneva, Switzerland, pp. 123-163.

Van Mele, P. 1998. Integrated fruit production of mango and durian in the eastern region of Thailand. Report on a short-term evaluation mission of the 'IPM in selected fruit trees' Thai-German project. Technical report No. 2 of the IPM in fruit project, KU Leuven, Belgium, 22 pp.

Van Mele, P. 1999. Living fences of orchards in Southern Vietnam. Non-Wood News, 6, 48-49.

Van Mele, P. and Cuc, N. T. T. 1999. Predatory Ants in Orchards in the Mekong Delta of Vietnam. In: Loke and S. S. Soetikno (eds) Proceedings of the International Symposium on Biological Control in the Tropics. CAB International, Serdang, pp. 118-122.

Van Mele, P. and Hai, T. V. 1999. Pesticide Use in Orchards in the Mekong Delta of Vietnam. In: Proceedings of the 5th International Conference on Plant Protection in the Tropics, Kuala Lumpur, March 15-18th, 1999, pp. 529-533.

Van Mele, P. and Phen, T. V. 1999. Utilization and management of orchard ground cover in the Mekong Delta, Vietnam. Proceedings of the 17th Asian-Pacific Weed Science Society Conference, Bangkok, November 22-27, 1999, pp. 296-302.

van Schoubroeck, F. 1999. Learning to fight a fly: developing citrus IPM in Bhutan. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 200.

Vijaysegaran, S. and Ibrahim, A. G. (eds) 1991. First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, 1988. MARDI, Kuala Lumpur.

VNS (Viet Nam News) 1996. Insecticides in Viet Nam are dangerous and out of control. Viet Nam News, July 30, p. 4.

VNS (Viet Nam News) 1998. Deaths show poisoning danger. Viet Nam News, December 24, p. 3.

VNS (Viet Nam News) 2000a. Land use increases, but with deforestation drawbacks. Viet Nam News, January 11, p. 4.

VNS (Viet Nam News) 2000b. VN population density third highest in region. Viet Nam News, January 13, p. 1.

Vos, J. 1998. Development of decision-making tools for vegetable farmers inSoutheast Asia. In: P. T. Haskell and P. McEwen (eds) Ecotoxicology: Pesticides and Beneficial Organisms. Chapman & Hall, London, pp.404-409.

Vromant, N., Rothuis, A. J., Cuc, N. T. T. and Ollevier, F. 1998. The effect of fish on the abundance of the rice caseworm *Nymphula depunctalis* (Guenée) (Lepidoptera: Pyralidae) in direct seeded, concurrent rice-fish fields. Biocontrol Science and Technology, 8, 539-546.

Vuong, L. V., Bich, M. T., Son, D. V., Bregman, L. and Gallagher, K. 1995. Evaluation Report: Tea IPM Development Program in Bac Thai Province. Nov 20-Dec 1, 1995. CIDSE, Hanoi, 24 pp.

Waage, J. 1998. Sustainable pest management in smallholder tree crops: farmers as IPM experts. CABI Bioscience/Global IPM Facility, Ascot, Berks, 5 pp.

Waage, J. 1999. Beyond the realm of conventional biological control: harnessing bioresources and developing biologically-based technologies for sustainable pest management. In: Loke and S. S. Soetikno (eds) Proceedings of the International Symposium on Biological Control in the Tropics. CAB International, Serdang, pp. 5-17.

Waibel, H. 1993. Government intervention in crop protection in developing countries. In: D. J. Chadwick and J. Marsh (eds) Crop Protection and Sustainable Agriculture. Wiley, Chisester, pp. 76-93.

Waterhouse, D. F. 1998. Biological Control of Insect Pests: Southeast Asian Prospects. ACIAR, Canberra, 548 pp.

Whittle, A. M. 1992. Diseases and pests of citrus in Viet Nam. FAO Plant Protection Bulletin, 40(3), 75-81.

Xuan, V. T. and Matsui, S. (eds) 1998. Development of Farming Systems in the Mekong Delta of Vietnam. Ho Chi Minh City Publishing House, Ho Chi Minh City, pp. 318.

Youm, O. and Baidu-Forson, J. 1995. Farmers' perception of insect pests and control strategies, and their relevance to IPM in pearl millet. In: K. F. Nwanze and O. Youm (eds) Panicle Insect Pests of Sorghum and Pearl Millet: Proceedings of an International Consultative Workshop. ICRISAT, Patencheru, India, pp. 291-296.

2. Farmers' knowledge, perceptions and practices in mango pest management in the Mekong Delta

Abstract

A survey of mango farmers' knowledge, perceptions and practices in pest management was conducted during the dry season of 1998 in the Mekong Delta, Vietnam. Identification and control of pests was often based on damage symptoms, rather than on sighting causal agents. Damage of the seed borer *Deanolis albizonalis* (Hampson) was often wrongly attributed to fruit flies *Bactrocera dorsalis* Hendel. Nearly all farmers applied calendar sprays of insecticides (97%) and fungicides (79%) from pre-flowering until harvest, with on average 13.4 and 11.6 applications per year, respectively. Pyrethroids were most popular (57%), followed by organophosphates (25%) and carbamates (15%). About 20% of the insecticides used belonged to WHO Toxicity Class I, the rest nearly all belonged to Class II. Half of all the target sprays were done with three pyrethroid products only. Farmers' estimated yield loss due to insect pests was strongly correlated to estimated pest severity. Due to pesticide sellers' recommendations, farmer's sprayload significantly increased from 26 to 37 sprays per year, whereas number of insecticide products used per farmer increased from 2.6 to 3.9 with advice from extension staff and media. Expenditure for pesticides was correlated with that of fertilizers. There was no relationship between the amount of money spent on pesticides and yield. On-farm research is needed to evaluate whether significant savings can be obtained given a more judicious use of pesticides. Only 10% of the 93 participating farmers knew about natural enemies, all of which were predators.

Introduction

The total fruit production area in the Mekong Delta, Vietnam increased from 92,000 ha in 1985 to 175,000 ha in 1995. During this period the government's policy has been to stress agricultural diversification, but conversion from paddy fields into fruit orchards is not actively stimulated because it might endanger Vietnams second position in the world rice export market. Conversion, however, is still taking place as many farmers prefer growing high value crops. After citrus and longan, mango is the third most important perennial fruit crop of the Mekong Delta, being cultivated over an area of 12,700 ha, and with an average yield of 9.3 tonnes per ha. In 1995, 66% of Vietnam's national gross output for mango was produced in the Mekong Delta (DAFF, 1996). Since the density of human population is very high, farming systems are quite intensive and diversified. Farmers often share resources for both their orchard and irrigated rice fields. Fish culture is sometimes combined with fruit or rice cultivation.

Worldwide, sustainability of agricultural systems has received more and more emphasis over the past decades, though successes have been highly dependent on type of crop and region (Mengech, *et al.*, 1995; Morse and Buhler, 1997). Perennial crops generally provide better opportunities to implement integrated pest management (IPM), due to their relatively stable ecosystems (Raheja, 1995). However, since perennial fruit crops are not considered as mandatory crops by the CGIAR, no large-scale, co-ordinated research on pest management has been undertaken. In Vietnam, efforts to stimulate IPM have been mainly limited to rice production and more recently to tea and vegetable production (Van Mele, 1998). Introduction of the IPM concept in tropical fruit production is a new development in most countries (DOA and DOAE, 1995; PCARDD, 1994; Waite, 1998).

One of the major constraints in establishing an IPM programme is the lack of adequate information about farmers' knowledge, perceptions and practices (KPP) in pest management (Heong, 1985; Teng, 1987; Morse and Buhler, 1997). If scientists have to work with farmers to improve crop production and crop protection, they should recognize farmers' constraints and their existing technical knowledge (Kenmore, 1991; Bentley, 1992; Morse and Buhler, 1997). Knowledge of pests vary between farmers working in similar or different agro-ecosystems. In some cases, pest recognition is a major problem, while in others knowledge about pest ecology is the major constraint (van Huis and Meerman, 1997). Generally, farmers have good knowledge about easily observable and important objects (Bentley, 1992). However, farmers and scientists may differ in their opinion about the importance of a particular pest. This has been especially true for leaf damaging pests in rice, to which farmers attribute substantial yield losses and subsequently target their sprays against these organisms (de Kraker, 1996; Heong and Escalada, 1997b; Mai *et al.*, 1997).

Evaluating farmers' knowledge and perception of pests and natural enemies is especially useful to set research agendas, for planning campaign strategies and developing messages for communication (Fujisaka, 1992; Escalada and Heong, 1993). Farmers' KPP in controlling rice pests have been well-documented (Fujisaka, 1990; Adesina *et al.*, 1994; Heong and Escalada, 1997b). Similar documentation is available for cotton (Ochou *et al.*, 1998), cashew (Nathaniels, 1998), vegetables (Pollard, 1991; Trutmann *et al.*, 1993, 1996; Burleigh *et al.*, 1998), and subsistence crops (van Huis *et al.*, 1982; Atteh, 1984; Chitere and Omolo, 1993; Bottenberg, 1995; Youm and Baidu-Forson, 1995), but it is non-existent for tropical fruit crops. Besides, relatively few scientific papers address farmers' pesticide use patterns, which in many cases in developing countries is a major component of pest management (Heong and Escalada, 1997b; Burleigh *et al.*, 1998).

Our survey focused on mango farmers' decision making, their knowledge, perception, and pest management practices. This information was used to (i) identify the pest problems that farmers perceive as most important; (ii) evaluate farmers' knowledge and practices in pest management, including farmers' pesticide use patterns; and (iii) identify gaps between research findings and farmers' practices.

Materials and methods

Study site

Three major fruit growing areas in the Mekong Delta, South Vietnam, were covered in the study, namely Can Tho, Dong Thap and Tien Giang Provinces. Mean annual rainfall in the study area ranges from 1,200 mm to 1,600 mm with the dry season lasting from November/December to April/May. Average elevation of these three provinces is between 0.5 and 1.5 m above sea level and large areas are prone to flooding during some periods of the year. The major soils of the fruit producing areas are alluvial soils that have high natural fertility. Fruit orchards are mainly established along riverbanks and in the vicinity of canals.

A ridge cultivation system, with raised beds of 2-13 m wide, on which 1 to 7 rows of fruit trees are grown, is most common. Planting beds are separated from one another by 1-8 m wide canals that are used for irrigation and transport of the harvested fruits. This cropping system is quite unique in the world and can elsewhere only be found in the lowland areas around Bangkok, Thailand (Othman and Suranant, 1995).

Survey

A survey was conducted from January to April 1998 in the major mango producing provinces. A total of 93 mango farmers were interviewed. Sampling was stratified; major mango growing districts within each of the three provinces were selected, and within each district orchards under production, with trees being four years or older, were chosen randomly. In Can Tho, Chau Thanh district was selected and in Dong Thap, Cao Lanh district. In Tien Giang province, Cai Lay, Cai Be and Chau Thanh districts were sampled.

The questionnaire aimed to assess socio-economic, agronomic and pest management aspects in order to get a clear picture of the agro-ecosystem, decision-making and implementing actions in pest management. Farmers' KPP related to pests, natural enemies and pest management received special emphasis. The content of the questionnaire and type of questions asked was agreed upon after key informant interviews. To evaluate farmer's pest perception, they were first asked to record the most important pest problems. For each of the major pests, pest incidence, pest severity and estimated yield loss was ranked on a 3-level scale (low, moderate and high). The questionnaire was pretested and revised. On average, each questionnaire took 2-3 hours of interview with each farmer, followed by a visit in the orchard. Since the period between flower induction and harvest takes 3-4 months, it was not always possible to cross-check farmers' answers regarding pest status with field observations. People involved in the survey were members of the Plant Protection Department, Cantho University. Survey data were encoded and statistical analysis were accomplished using SPSS statistical software. Percentages were based on the number of respondents rather than using the total sample. In cases where multiple responses were obtained, total sample size was used. Both parametric and non-parametric tests were conducted. The detailed procedures used are given in the text and the tables.

Results

Farmer profile

Table 1 summarizes the socio-economic profile of the farmers interviewed. Slightly more than 40% of the farmers were older than 50 years, and attended school for only 1 to 5 years, though age and educational level were not correlated. About 19% of the farmers interviewed had attended an extension course. Around 50% of the orchards selected were established more than 10 years ago, indicating the farmers' years of experience in mango cultivation, except for those few cases where sons took over from fathers.

Orchard profile

About 90% of the orchards were converted paddy fields (Table 1). Two-thirds of the orchards were less than 0.5 hectare with nearly 80% under monocrop. Of those orchards under mixed cropping, 37% were mango mixed with longan (*Dimocarpus longan* Lour.), 32% with water apple (*Syzigium aqueum* Alston) and 21% with lime (*Citrus aurantifolia* Swing). Implementation of IPM has only been successful in those cases where the same crop was cultivated over a wide area (Morse and Buhler, 1997). This stresses the importance for small-scale Vietnamese fruit farmers to co-operate on a regional-wide basis. Major varieties covered in our survey were *Ghep* (71%), *Cat Hoa Loc* (18%) and *Cat Chu* (14%). *Cat Hoa Loc* was mainly restricted to Can Tho. Orchards in this Province were significantly older ($P<0.05$), larger ($P<0.001$) and consisted more of a mixture of different mango varieties

(Cramer's V=0.35, P<0.01) compared to the other two Provinces. About one-third of the farmers bought seedlings from a nursery, and up to 85% of the trees were grown on their own rootstock. Animal husbandry was practiced among 30% of the farmers, which consisted mainly in rearing fish in the temporarily closed canals of their orchard.

There was no difference in farmer age or education level between the different Provinces, but farmers in Tien Giang had significantly more attended extension courses.

Table 1. Profile of mango farmers and orchards in different provinces of the Mekong Delta, Vietnam, 1998 .

	Can Tho n=9	Dong Thap *n*=47	Tien Giang *n*=37	Tests[1]
Age farmer (years)	45.3	47.2	52.0	NS
Education (years of school)	7.3	7.6	7.5	NS
Extension (% attended courses)	0.0	13.0	32.4	V=0.28*
Age orchard (% >10 years)	88.9	43.4	51.4	V=0.26*
Field history (%)				
paddy field	100.0	87.2	86.5	V=0.20
waste land	0.0	4.3	8.1	V=0.11
other orchard	0.0	8.5	5.4	V=0.11
Orchard size (ha)	1.5	0.6	0.5	Var***
Plant density (trees/ha)	231	382	460	Var*
Age trees (year)	15.0	11.6	11.2	NS
Cropping pattern (%)				
two or more varieties	55.6	10.9	13.5	V=0.35**
mixed crops[2]	33.3	13.0	18.9	V=0.16
animal integration	44.4	37.0	18.9	V=0.21
Major varieties[3] (%)				
Cat Hoa Loc	55.6	21.7	5.4	V=0.37**
Cat Chu	22.2	15.2	10.8	V=0.10
Ghep	11.1	65.2	91.9	V=0.51***
Hon Xanh	55.6	0.0	2.7	V=0.66***

[1] Tests conducted were one-way ANOVA (Var) or Chi-squared with Cramer's V to indicate strength of relation. NS = not significant, * significant at 5% level, ** at 1% level and *** at 0.1% level.
[2] Include rose apple (Can Tho and Tien Giang), longan (Dong Thap and Tien Giang) and lemon (Dong Thap).
[3] Sum of different varieties can be larger than 100% due to occurrence of more than 1 variety in some of the orchards.

Farmers' knowledge and perception of pests and natural enemies

Insect pests

In response to the question concerning the major insect pests in their orchard, farmers on average mentioned 3.9 (SE=0.2) different species. They described pests mostly as related to a particular symptom or by the plant part under attack.

The seed borer, *Deanolis albizonalis* (Hampson) (Lepidoptera: Pyralidae), was mentioned by 89% of the farmers (Table 2). Hoppers, *Idioscopus* spp. (Homoptera: Cicadellidae), were reported by 73%, and shoot borers, *Chlumetia transversa* (Walker) (Lepidoptera: Noctuidae) and one other unidentified species, by 56% of the farmers. About 27% and 20% of the farmers mentioned flower-feeding and leaf-feeding caterpillars (Lepidoptera: Lymantriidae), respectively. Scales (Homoptera: Coccidae, Diaspididae) and mealybugs (Homoptera: Pseudococcidae), were described by one-quarter of the farmers under the common name *rep sap*, whereas some farmers used *rep dinh* to describe scales. About 15% of the farmers reported problems with the fruit fly, *Bactrocera dorsalis* Hendel (Diptera: Tephritidae). The leaf webber caterpillar, *Orthaga* sp. (Lepidoptera: Pyralidae) was only mentioned by farmers in Dong Thap and the bark borer, *Plocaederus* sp. (Coleoptera: Cerambycidae) nearly only by farmers in Can Tho.

Farmers' estimates of severity and yield loss due to the seed borer and flower-sucking hoppers were rated significantly higher in Can Tho Province (Table 3). Mealybug incidence had a higher rating in Tien Giang Province. In general, pest incidence was correlated with pest severity (Kendall's tau-b=0.40, $P<0.001$). Estimated yield loss due to insect pests was strongly correlated to estimated pest severity (Kendall's tau-b=0.75, $P<0.001$).

Diseases

Estimated yield losses for diseases were generally higher than for pests. Most frequently reported disease was *than thu*, referring to anthracnose *Colletotrichum gloeosporioides* (Penz.) Sacc. (Table 2). Frog skin spot or *da ech* (of unknown etiology) was mentioned by about 62% of the farmers in Dong Thap and 25% in Tien Giang. Total absence of this disease in Can Tho might be due to varietal differences. Farmers' description of a symptom sometimes referred to a particular disease such as sooty mould (*bo hong*) caused by *Capnodium* sp., whereas the symptom of fruit burn (*da cam*) could be due to causes ranging from sunburn, mites, thrips to scab. This symptom was reported by 33% of the farmers as a disease.

Table 2. Percentage of farmers recording major mango pests and spray targets in different provinces of the Mekong Delta, Vietnam,1998.

Common English name[1]	Local name	Can Tho		Dong Thap		Tien Giang	
		Pest	Target	Pest	Target	Pest	Target
Pests							
Seed borer	Sau duc trai	100.0	88.9	91.5	87.2	80.6	75.0
Fruit fly	Ruoi duc trai	44.4	22.2	4.3	-	19.4	13.9
Flower-sucking hopper	Ray an bong	77.8	44.4	74.5	55.3	-	-
Flower-sucking hopper	Ray bong	22.2	11.1	-	-	77.8	66.7
Leaf-sucking hopper	Ray chich la	11.1	-	8.5	-	-	-
Green hopper	Ray nha	-	-	2.1	2.1	5.6	5.6
Flower-feeding caterpillar	Sau an bong	77.8	66.7	17.0	14.9	27.8	22.2
Flower-feeding caterpillar	Sau duc bong	22.2	22.2	-	-	-	-
Mealybugs and scales	Rep sap	55.6	33.3	17.0	10.6	30.6	22.2
Scales	Rep dinh	11.1	-	-	-	5.6	5.6
Shoot borer	Sau duc canh	-	-	68.1	46.8	58.3	41.7
Shoot borer	Sau duc ngon	-	-	2.1	2.1	2.8	2.8
Bark borer	Sung duc than	77.8	22.2	2.1	-	5.6	2.8
Twig borer	Bu xe	-	-	8.5	2.1	2.8	2.8
Leaf-feeding caterpillar	Sau an la	66.7	55.6	12.8	4.3	19.4	13.9
Leaf webber	Sau o	-	-	25.5	19.1	-	-
Leaf-feeding weevil	Bo an la	-	-	6.4	4.3	-	-
Termites	Moi	-	-	2.1	-	8.3	8.3
Diseases							
Anthracnose	Than thu	88.9	55.6	53.2	44.6	50.0	33.3
Sooty mould	Bo hong	77.8	44.4	57.4	42.6	33.3	8.3
Frog skin spot	Da ech	-	-	61.7	34.0	25.0	22.2
Fruit burning	Da cam	44.4	22.2	46.8	23.4	13.9	13.9
Ring spot	Dom vong	-	-	-	-	38.9	33.3
Brown spot	Dom den vo khuan	77.8	55.6	-	-	2.8	-
Trunk canker	Chay mu goc	-	-	8.5	-	5.6	2.8
Dead of branch	Kho canh	22.2	-	4.3	2.1	-	-
Fruit rot	Thoi trai	11.1	11.1	4.3	2.1	2.8	-
Leaf spot	Dom la	11.1	-	-	-	5.5	2.8

[1] Some pests could only be identified up to family level, some local names even refer to different pests belonging to different families. Scientific names are given in the text whenever possible.

Natural enemies

Only about 10% of the farmers had any knowledge about natural enemies, all of which were predators. When asked how they knew about them, the only answer was that they had learned through their own observations. Six farmers mentioned spiders, two mentioned the weaver ant *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae), and one reported swallows.

Pest management practices

Three farmers manually removed larvae of the shoot and bark borer, one farmer cut flowers infested with scales or nymphs of hoppers. The majority (73.1%) of farmers pruned, mainly to control the shoot or twig borer. Nearly all (97%) farmers used insecticides, and 79% used fungicides. About half of them possessed a knap-sack sprayer, and the other half had a power sprayer. Only one farmer spot-sprayed his trees after observing a high pest incidence. All the others applied total cover sprays.

Timing and frequency of pesticide applications

Insecticides were used at an average of 13.4 (SE=0.7) sprays per year ranging from 10 to 42, and fungicides were applied from 8 to 21 times per year, with at an average of 11.6 (SE=0.6). Most sprays were applied from a few weeks before flowering (September/October) until harvest (February-April), and fungicides were often mixed with insecticides. Nearly all of the farmers calendar sprayed on a weekly basis. Some even sprayed at 3-4 days intervals, mainly to protect fruits from seed borer infestation. Nearly 50% of the farmers still sprayed insecticides one to two weeks prior to harvest, about one-third still applied fungicides. No monitoring was done and therefore sprays were merely prophylactic.

Some farmers who knew about natural enemies had a different attitude towards pesticides. On average, the majority (6 out of 9) of them sprayed insecticides only 5.5 (SE=1.2) times a year. The farmer who described both weaver ants and swallows as natural enemies sprayed only twice a year with insecticides.

Table 3. Percentage of farmers estimating incidence, severity and yield loss of major mango insect pests in different provinces of the Mekong Delta, Vietnam.

Pest	Incidence			Cramer's V[1]	Severity			Cramer's V	Yield loss			Cramer's V
	CT[2]	DT	TG		CT	DT	TG		CT	DT	TG	
Seed borer												
low	0	0	7		0	38	39		14	42	27	
moderate	13	36	26	0.19	50	62	50	0.38***	29	58	41	0.43***
high	87	64	67		50	0	11		57	0	7	
Flower-sucking hopper												
low	13	9	0		0	42	26		0	58	80	
moderate	25	41	35	0.17	38	29	57	0.29*	20	23	20	0.44***
high	62	50	65		62	29	17		80	40	0	
Flower-feeding caterpillar												
low	0	0	0		17	29	67		0	43	70	
moderate	33	43	70	0.32	33	71	33	0.53*	60	57	20	0.46+
high	67	57	30		50	0	0		40	0	10	
Leaf-feeding caterpillar												
low	20	0	33		20	75	50		0	100	83	
moderate	0	60	67	0.55*	40	25	50	0.44	50	0	17	0.59
high	80	40	0		40	0	0		50	0	0	
Mealybugs and scales												
low	100	17	22		100	80	33		100	100	62	
moderate	0	67	22	0.58*	0	20	44	0.41	0	0	17	0.38
high	0	16	56		0	0	22		0	0	11	
Shoot borer												
low	0	17	19		0	59	50		0	100	72	
moderate	0	48	48	0.05	0	34	44	0.10	0	0	17	0.36
high	0	35	33		0	7	6		0	0	11	

[1] Chi-squared was used to test significance. NS = not significant, + = significant at 10% level, * significant at 5% level, ** at 1% level and *** at 0.1% level.

[2] CT = Can Tho, DT = Dong Thap and TG = Tien Giang Province.

Pesticide use

The majority of farmers (80.5%) mixed different insecticide products. On average, farmers targeted sprays against 3.3 (SE=0.2) insect pests. From a total of 2073 intended targets, 33% were seed borer, 26% flower-sucking hoppers, 15% shoot borers, 8% flower-feeding caterpillars and 5% scales. More than 10% of the sprays targeted leaf-damaging insects (Table 4). The average number of insecticide products used per farm was 3.0 (SE=0.1). A total of 36 different insecticide products were used including 26 different active ingredients. Alpha-cypermethrin and cypermethrin were used under 4 and 7 different trade names, respectively. This has seemingly confused some farmers as they mixed products with the same active ingredient.

About 20% of the insecticides used belonged to WHO Toxicity Class I, the rest nearly all belonged to Class II. Pyrethroids were most popular (57%), followed by organophosphates (25%) and carbamates (15%) (Table 4). Still more than 12% of the target sprays were of banned or restricted organophosphates, targeting several different pests.Half of all the target sprays was done with three pyrethroid products only, cypermethrin, esfenvalerate and lambda-cyhalothrin. More than 50% of all farmers in each of the provinces used cypermethrin (Table 5)

A total of 18 different fungicides were used, including 11 different active ingredients. Major products used belonged to the group of systemic benzimidazoles, namely carbendazim (28.7%) and thiophanate-methyl (10.2%), and the group of dithiocarbamates, namely mancozeb (14%) and propineb (8.9%). Products belonging to other groups were chlorothalonil (9.6%) and metalaxyl (9.6%). Except for metalaxyl, which belonged to WHO Toxicity Class III, all fungicides belonged to Class IV. From a total of 157 intended targets, 25% were anthracnose, 20% were sooty mould, 18% were frog skin spot and 17% were fruit burn.

Farmers' perception of pesticide advantages and disadvantages

Asking about the criteria on which farmers make decisions to choose a particular pesticide, a fast knock-down effect of the product scored highest (68%), followed by familiarity (19%). Mango farmers were quite satisfied with the insecticides applied, as estimated efficiency ranged between 65% and 80%. Despite the high spray frequency with pyrethroids, farmers attributed a rather low insecticide efficiency against the mango seed borer. Lowest insecticide efficiency was reported against scales and mealybugs. About sixty percent of the sprays targeting scales and mealybugs were with organophosphates (Table 4). Disease control with fungicides was less efficient, ranging between 51% and 73%. Nearly 85% of the farmers applied KNO_3 to induce early flowering and produce off-season fruits. Flowering thus took place in the rainy season (September-November), making them more vulnerable to diseases. As fruit burn was wrongly diagnosed, control efficiency was rather low (53%). Mites and thrips were probably the causal agents, not fungi.

The advantages related to insecticide use (number of replicants = 27) were the good control provided by the product (100%), ease of use (19%) and ease of purchase (11%). From a total of 20 replicants, 80% mentioned health problems and 35% the difficulty of spraying very high trees as disadvantages.

Generally, Asian farmers perceive chemical inputs as being necessary to obtain high yields. To check whether similar conclusions could be made for mango farmers, we conducted a multiple regression analysis. Variance in yields, as reported by farmers, could be mainly explained by a model (r^2=0.34, $P<0.001$) combining age of the trees (standardized regression coefficient B=0.43, $P<0.001$) and fertilizer expenditure (B=0.27, $P<0.01$). Expenditure for pesticides was correlated with that of fertilizers (Pearson r=0.32, $P<0.01$). Yield did not seem to be influenced by the amount of money spent on pesticides (B=0.08, P=0.45).

Information transfer

To understand the major influences on farmers' decision making, they were asked about their major sources of pesticide advice. Regional differences occurred (Figure 1). Farmers in Can Tho relied mainly on their own experience (89%) and media advertisements (56%), whereas pesticide sellers were significantly more reported by farmers in Dong Thap and Tien Giang Province (Cramer's V=0.23, $P<0.05$). They were less important in Can Tho as mango is a minor crop in this Province. Hence pesticide sellers have mainly concentrated their efforts on other crops such as rice and vegetables. The Extension Service was most significant in Tien Giang Province, clearly influenced by the presence of the Southern Fruit Research Institute (Cramer's V=0.35, $P<0.01$).

In general, the majority (71%) reported 'trusting on their own experience' for pesticide advice. As nearly all mango farmers excessively used pesticides and a fast knock-down effect was their major pesticide criterion, building on their own experience is a rather negative aspect. Besides, the information source of their own experience was correlated with pesticide advertisings in the media (Cramer's V=0.24, $P<0.05$). About 44% of the farmers obtained advice from the pesticide advertisings in the media and an equal amount from the pesticide sellers (multiple answers). Extension staff and neighbours were less important (18%) sources of information. A strong correlation (gamma=0.84, P<0.001) existed between attending extension courses (no course, 1 or 2 courses and more than 2 courses attended) and relying on extension staff for pesticide advice.

Table 4. Insecticides used by farmers against mango target pests in the Mekong Delta, Vietnam.

Insecticides	WHO toxicity class[2]	Target mango pests and % of insecticide used against targets[1]								Total	
		LW	LC	ME	FF	SHB	FH	FC	SB	no.	%
Organophosphates											
Methyl parathion	Ia	0.0	0.0	15.2	0.0	0.0	2.7	0.0	0.0	30	1.4
Methamidophos	Ib	3.1	6.5	0.0	15.7	3.3	1.6	0.0	1.8	49	2.4
Monocrotophos	Ib	19.9	0.0	5.1	0.0	14.4	2.2	5.0	2.8	120	5.8
Dichlorvos	Ib	0.0	0.0	0.0	0.0	5.2	0.0	10.1	5.5	69	3.3
Methidathion	Ib	0.0	10.4	25.3	0.0	0.0	15.9	8.8	2.4	150	7.2
Diazinon	II	0.0	0.0	14.1	0.0	0.0	9.5	0.0	4.6	97	4.7
Carbamates											
Fenobucarb	II	12.4	0.0	35.4	31.4	15.1	11.5	9.4	8.8	254	12.3
Carbaryl	II	0.0	0.0	0.0	0.0	0.0	8.6	0.0	2.2	62	3.0
Pyrethroids											
Alpha-cypermethrin	II	0.0	0.0	0.0	7.8	0.0	8.0	0.0	6.5	92	4.4
Cypermethrin	II	8.7	32.5	0.0	0.0	25.2	22.3	47.2	21.5	458	22.1
Deltamethrin	II	0.0	0.0	0.0	0.0	2.6	0.0	0.0	3.1	29	1.4
Esfenvalerate	II	55.9	23.4	0.0	19.6	12.1	10.2	8.8	17.1	340	16.4
Lambda-cyhalothrin	II	0.0	27.3	5.1	25.5	21.0	2.0	9.4	20.5	267	12.9
Others											
Fipronil	II	0.0	0.0	0.0	0.0	0.0	2.2	0.0	1.5	22	1.1
Buprofezin	III	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	12	0.6
Ethofenprox	IV	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	17	0.8
Cypermethrin profenofos	II	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	2	0.1
Fenvalerate dimethoate	-	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	3	0.1
Total no.		161	77	99	51	305	547	159	674	2073	100.0

[1] Many farmers applied insecticides for more than one pest at a time. Percentage of target sprays is based on total number of target sprays for each pest, given at the bottom of each column.
[2] Ia = extremely hazardous, Ib = highly hazardous, II = moderately hazardous, III = slightly hazardous, IV = unlikely to present acute hazard in normal use, - = unclassified. Source: Anonymous, 1999.
LW = leaf webber, LC = leaf-feeding caterpillar, ME = mealybugs and scales, FF = fruit fly, SHB = shoot borer, FH = flower-sucking hopper, FC = flower-feeding caterpillar, SB = seed borer.

Table 5. Percentage of mango farmers using different insecticides in three different provinces of the Mekong delta, Vietnam.

Insecticides	Can Tho	Dong Thap	Tien Giang	Cramer's V[1]
Organophosphates				
Methyl parathion	22.2	0.0	8.1	0.30*
Methamidophos	33.3	2.1	13.5	0.32**
Monocrotophos	33.3	10.6	13.5	0.20
Dichlorvos	0.0	2.1	2.7	0.05
Methidathion	0.0	12.8	24.3	0.21
Diazinon	11.1	8.5	10.8	0.04
Fenitrothion	22.2	4.3	0.0	0.31*
Dimethoate	0.0	6.4	0.0	0.18
Carbamates				
Fenobucarb (BPMC)	11.1	23.4	27.0	0.11
Carbaryl	0.0	2.1	13.5	0.24+
Pyrethroids				
Alpha-cypermethrin	66.7	21.3	13.5	0.36**
Cypermethrin	55.6	53.2	56.8	0.03
Deltamethrin	33.3	25.5	10.8	0.20
Esfenvalerate	11.1	53.2	29.7	0.30*
Lambda-cyhalothrin	0.0	10.6	45.9	0.43***
Others				
Fipronil	0.0	4.3	0.0	0.15
Buprofezin	0.0	2.1	2.7	0.05
Ethofenprox	0.0	2.1	5.4	0.11
Cypermethrin + profenofos	0.0	2.1	2.7	0.05
Fenvalerate + dimethoate	22.2	2.1	0.0	0.36**
Fenobucarb + phenthoate	11.1	4.3	2.7	0.12

[1] Chi-squared was used to test significance: + = significant at 10% level, * significant at 5% level, ** at 1% level and *** at 0.1% level.

GLM general factorial analysis (main effects) were conducted to find out which production characteristics and pesticide information sources discriminated best for differences in the number of pesticide products and sprays applied. Only information sources seemed to be significant. More different pesticide products were applied by farmers getting pesticide advice from the extension staff (regression coefficient B=0.65, P=0.08) or media (B=0.52, P=0.07). The number of insecticide products used per farmer increased from 2.6 (SE=0.2) to 3.9 (SE=0.2) when relying both on extension staff and media for pesticide advice. Farmers getting advice from extension sprayed less frequently (B=-3.32, P=0.07), but overall sprayload was not influenced. Farmers' sprayload was higher for those relying on their own experience (B=9.98, P=0.05) or the pesticide seller (B=10.10, P=0.03). Due to pesticide sellers' recommendations, farmers' sprayload increased from 26.0 (SE=3.1) to 36.8 (SE=3.6) sprays per year.

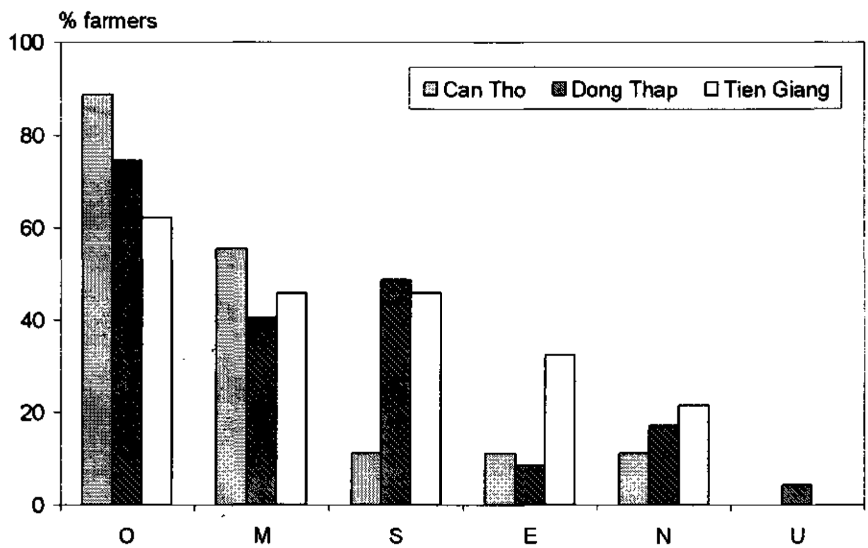

Figure 1. Regional differences in sources of pest management information influencing farmers' decision-making. O=own experience, M=media, S=pesticide seller, E=extension officer, N=neighbour, U=university staff.

Discussion

Knowledge and perceptions of pests and natural enemies

The major mango pests reported by farmers in the Mekong Delta have also been described as major problems in Indonesia and the Philippines (Cunningham, 1984; PCARRD, 1994), and in Thailand with exception of the seed borer (DOA and DOAE, 1995). Differences in pest perception occurred between provinces. Shoot borers (*sau duc canh* and *sau duc ngon*) were not mentioned by farmers in Can Tho Province. This might be due to a variety of reasons such as differences in size and age of the trees, which makes observations more difficult, and differences in varieties, cropping system, or geographical distribution of the pest. Farmers in Can Tho Province perceived leaf-feeding caterpillars as more problematic compared to farmers in other provinces. This could be attributed to the fact that mango farmers in Can Tho lacked proper training, as was also the case for citrus in this province (Chapter 6).

Some farmers (*n*=6) made a distinction between a flower-sucking hopper (*ray an bong*) and a leaf-sucking hopper (*ray chich la*). It is possible that different hoppers occur. However, flower-sucking hoppers are already causing damage during the flushing stage, after which they gather on the underside of mature leaves (DOA and DOAE, 1995). That pests are considered one at a time, with no attempt to view them in an integrated sense, is one of the characteristics that equates much more closely to pest control than pest management (Morse and Buhler, 1997). It might also indicate that farmers pay no or less attention to pests during the vegetative phase.

During our survey, about 15% of the farmers reported problems with fruit flies, which according to the farmers could highly reduce yields. However, during field studies from 1994 to 1996, fruit flies occurred in fewer than 2% of the mango orchards, and therefore are not considered a serious problem in mango in the Mekong Delta of Vietnam (Cuc *et al.*, 1998). Therefore farmers have most likely confused fruit fly damage with that caused by the seed borer. A few years ago, confusion between these two pests was very common, but through media and extension activities, this situation has in general improved (Cuc, pers. comm., 1999). None of the farmers reporting fruit flies had ever attended an extension course. Waterhouse (1998) found it remarkable that there are so very few references to mango seed borer in the literature and postulated that the damage actually due to the seed borer is commonly attributed to other causes.

Generally, farmers' knowledge about diseases was less extensive than their knowledge about insects and attributed yield losses due to diseases were higher. The symptom of fruit burn (*da cam*) could be due to a variety of causes such as sunburn, mites, thrips or scab. This symptom was reported as a disease by 33% of the farmers, mainly in Can Tho and Dong Thap Province. In these two provinces citrus is a popular crop with mite damage symptoms equally described as *da cam* disease by untrained farmers (Chapter 6). About 20% of the fungicide sprays targeted this symptom in mango. This illustrates that also mango farmers do not always make the link between causal agent and damage symptom, and therefore often erroneously treat symptoms. This missing link is particularly common in respect to smaller organisms such as diseases (Bentley, 1992; Trutmann *et al.*, 1996; van Huis and Meerman, 1997) and mites (Chapters 6 and 7). Farmers attribute symptoms of anthracnose on leaves to a disease. Symptoms of anthracnose on flowers, on the other hand, were not attributed to a disease, but to humid, foggy mornings. In the Central African highlands, farmers often related bean disease symptoms to the effects of various forms of moisture (Trutmann *et al.*,1996). Cashew farmers in Tanzania attributed powdery mildew (*Oidium anacardii*) to mist (Nathaniels, 1998).

Mango farmers in the Mekong Delta have no knowledge of the existence of smaller organisms such as predatory mites, parasitoids or entomopathogens, because they are difficult to observe (Bentley, 1992), or because their effect is difficult to interpret. Only a few farmers perceived some larger, predatory species in their mango orchard. The general high size of mango trees is possibly a limiting factor in farmers' perception and hence knowledge acquisition. In Malaysia, the weaver ant *O. smaragdina* is an important predator of the large mango tip borer *Penicillaria jocosatrix* (Guenee) (Lepidoptera: Noctuidae) (Khoo *et al.*, 1993). Also in citrus in the Mekong Delta, *O. smaragdina* is an important predator and therefore actively taken care of (Chapter 4). Besides, this ant species is widely known by all people in the Mekong Delta, also by non-farmers. Despite *O. smaragdina* being present in 10 mango orchards, it was surprising that only two farmers perceived it as beneficial. Training of farmers should definitely take this lack of knowledge or appreciation into account.

Pest management

In the Mekong Delta, the pattern of pesticide use in mango is very similar to that in rice, with 99% and 76% of the rice farmers spraying insecticides and fungicides, respectively (Heong and Escalada, 1997b). The fact that most orchards are converted paddy fields and that many farmers share their resources for both irrigated rice fields and orchards might explain this similar pattern of pesticide use. Fear of yield loss, commercial advertisings of chemical companies, lack of information or lack of knowledge about pests and natural enemies are some of the factors which can lock farmers into calendar spraying (Escalada and Heong, 1993; Norton, 1993; Schwab, 1995), as is the case for mango farmers in the Mekong Delta.

In rice, farmers' pesticide decisions do not seem to be based on economic rationale. These decisions, often made under uncertainty, are influenced more by perceptions of the pest and expected benefits from spraying (Waibel, 1986; Heong *et al.*, 1994; Heong and Escalada, 1997b). In mango, yield did not seem to be influenced by the amount of pesticides applied. Evaluation of whether significant savings can be obtained given a more judicious use of pesticides is recommended.

Pesticides were primarily used for prevention, as when targeting the seed borer, or after observing damage symptoms, for instance in case of leaf-damaging pests. Similarly, rice farmers overreact to leaf-feeding insects, since they strongly believe that these pests reduce yield (Heong *et al.*, 1994; de Kraker, 1996; Mai *et al.*, 1997). Some mango farmers equally targeted leaf-feeding caterpillars and leaf webbers. Farmer participatory experiments should be conducted to evaluate whether these pests affect the yield or not. In the Philippines, Golez (1991) effectively controlled the mango seed borer with 4 applications of cyfluthrin or deltamethrin at 60, 75, 90 and 105 days after fruit induction. Both in the Philippines and Australia, all major mango pests and diseases combined can be controlled with five to eight pesticide applications, when they are properly timed (Bondad, 1989; Cunningham, 1989; PCARRD, 1994). Numerous pesticide applications could also probably be saved in Vietnam, given a better knowledge of the pests and a more realistic estimate of the damage being caused.

Mango farmers have a tendency to spray insecticides with a fast knock-down effect, as has been described earlier for rice farmers (Heong and Escalada, 1997b; Normiyah and Chang, 1997). Besides, at least for the Mekong Delta, this mentality remained unchanged even after farmers had attended IPM courses in a farmer field school (Chung and Dung, 1996).

From 1994 to 1998, the number of pesticide products, mainly pyrethroids, used by fruit farmers in the Mekong Delta has increased by nearly 200% (Van Mele and Hai, 1999), illustrating the high interest chemical companies have in the Vietnamese market. In many industrialized countries, the excessive use of synthetic pyrethroids in tree fruit crops has lead to pest resistance, a decrease in natural enemies and increased problems with scales and mealybugs (Waite, 1998). The use of the banned and restricted products methyl parathion, monocrotophos and methamidophos has decreased by 50%, but is still substantial (Van Mele and Hai, 1999). Although methyl parathion was no longer supposed to be imported in Vietnam, residual stocks were still available. Anonymous (1997) described a lack of policy or enforcement of legislation on the import of chemicals as one of the existing problems to introduce IPM in Vietnam. Broad-spectrum insecticides can cause a resurgance of scales and evoke outbreaks of secondary pests such as thrips and mites, which in turn require further chemical treatments (De Faveri and Brown, 1995, Waite, 1998). Besides, continued use of the same insecticides has already caused resistance of scales against several organophosphates and carbamates (Grafton-Cardwell and Reagan, 1995; Waite, 1998).

Pesticide information sources

In rice in Vietnam, the excessive use of insecticides seems to be associated with prominent advertisings (Mai *et al.*, 1993). Marketing techniques of the chemical industry obviously have a very strong influence on farmers' choice to use chemicals as the only solution to avert the risk of pests. No attention is paid to products available on the market being toxic to highly toxic. Pesticides are always promoted on their curing effects and their poisonous effects are often neglected. Communication media has, on the other hand, been successfully applied to change rice farmers' pest management practices in the Mekong Delta (Heong *et al.*, 1998).

It is well recognized that pesticide sellers have a stronger presence than extension agents in many farming communities and are sought by farmers for advice because of their accessibility (Heong and Escalada, 1997a; Chapter 6). In many developing countries, major shortcomings of the extension service are responsibility for numerous other tasks, lack of adequate training, material shortages, centralist decision-making structures combined with a poor 'top-down' flow of information, and that extension messages are not in line with farmers' needs (Daxl *et al.*, 1994). Similar shortcomings for IPM extension in Thai fruit production were described by Nayman (1990). Farmer participatory IPM is proving an effective means of building successful farmer extension systems on the scale necessary to meet the needs of small holders in developing countries (van de Fliert, 1993; Matteson, 1996; Stock, 1996; Waage, 1998).

In the Philippines and Thailand, many rice farmers admitted that seeing their neighbours spraying their field often prompts them to spray as well, even though not necessary (Escalada and Heong, 1993). Fields with annual crops have open habitats making social control and interpersonal contacts an important factor in information exchange. This is true both for pesticide misuse (Escalada and Heong, 1993; Burleigh *et al.*, 1997; Tjornhom *et al.*, 1997) as for the spread of sound IPM practices (van de Fliert, 1993; Heong and Escalada, 1997a; Heong and Escalada, 1998). Orchards are, however, more closed habitats and every farmer can act more freely as he thinks is best. Physical or visual barriers and competition between farmers, among other reasons, make that farmer-to-farmer exchange of information is less common in fruit production in the Mekong Delta (Chapters 6 and 8). This situation necessitates even more the need of proper farmer training. Farmer-to-farmer learning could afterwards also be enforced through existing farmers' associations or other local organizations.

The importance of distilling information from a high science to a low-technology level by creating easily testable hypotheses, so called heuristics, has been proven to be very successful in information transfer to rice farmers (Castillo, 1996; Heong and Escalada, 1998). As research on fruit crops in Vietnam is in its infancy, it would take too much time to create heuristics that are based on accurate scientific knowledge of the agro-ecosystem. Based on both farmers' KPP and currently available scientific knowledge, farmer participatory research and extension activities should be developed. Farmers' involvement from the early stages of research will reduce the risk of their becoming lost in the labyrinth of research, or ending up with integrated pest management packages that are rejected by farmers (Morse and Buhler, 1997).

Mango farmers in the Mekong Delta, Vietnam, have so far been convinced and stimulated to use chemical inputs as the only means of crop production and protection. Pesticide advertising in the media, pesticide sellers and in many cases extension officers have created and promoted this tendency. It is urgently required to start with participatory research and mass media campaigns to show farmers that alternative, more sustainable approaches for pest and disease management are possible.

References

Anonymous 1997. National IPM meeting. FAO Intercountry Programme, Hanoi, 27-28 March 1997. MARD, Hanoi, 27 pp.

Anonymous 1999. Database on pesticides and the environment. Economic and Social Commission for Asia and the Pacific (ESCAP), Centre de co-opération Internationale en Recherche Agronomique pour le Développement (CIRAD), Commission of the European Union (EU). http://www.fadinap.com/pesticide.

Adesina, A. A., Johnson, D. E. and Heinrichs, E. A. 1994. Rice pests in the Ivory Coast, West Africa: farmers' perceptions and management strategies. International Journal of Pest Management, 40, 293-299.

Atteh, O. D. 1984. Nigerian farmers' perception of pests and pesticides. Insect Science and Its Application, 5, 213-220.

Bentley, J. W. 1992. The epistemology of plant protection: Honduran campesino knowledge of pests and natural enemies. In: R.W. Gibson and A. Sweetmore (eds) Proceedings of a Seminar on Crop Protection for Resource-Poor Farmers. CTA/NRI, pp. 107-118.

Bondad, N. D. 1989. The mango (especially as observed in the Philippines). Rex Book Store, Manila, pp. 402.

Bottenberg, H. 1995. Farmers' perceptions of crop pests and pest control practices in rainfed cowpea cropping systems in Kano, Nigeria. International Journal of Pest Management, 41, 195-200.

Burleigh, J. R., Vingnanakulasingham, V., Lalith, W. R. B. and Gonapinuwala, S. 1998. Pattern of pesticide use and pesticide efficacy among chilli growers in the dry zone of NE Sri Lanka (System B): perception vs reality. Agriculture, Ecosystems & Environment, 70, 49-60.

Castillo, G. T. 1996. Riding on a 'nem wave' of agricultural R&D: research in Asia. In: P. L. Pingali and T. R. Paris (eds) Competition and conflict in Asian agriculture resource management: issues, options and analytical paradigms. IRRI Discussion Paper Series No. 11. International Rice Research Institute, Manila, pp. 10-31.

Chitere, P. O. and Omolo, B. A. 1993. Farmers' indigenous knowledge of crop pests and their damage in western Kenya. International Journal of Pest Management, 39, 126-132.

Chung, D. K. and Dung, K. T. 1996. Pest Management in Rice Production in Vietnam: a Socioeconomic Assessment. Hanoi Agricultural University, Hanoi, pp. 67.

Cuc, N. T. T., Hung, N. V. and Dien, L. Q. 1998. Insect pests on citrus, durian, longan and mango in selected provinces of the Mekong Delta of Vietnam. In: P. Van Mele and N. V. Huynh (eds) Proceedings of the First Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management. Cantho University, Can Tho, pp. 71-76. (in Vietnamese).

Cunningham, I. 1984. Mango insect pests. In: Proceedings of the First Australian Mango Research Workshop. Queensland DPI, Brisbane, pp. 211-224.

Cunningham, I. 1989. Pests. In: J. Bagshaw (ed.) Mango pests and disorders. Queensland DPI, Brisbane, pp. 10-21.

DAFF (Department of Agriculture, Forestry and Fishery) 1996. Statistical Data of Agriculture, Forestry and Fishery 1985-1995. Statistical Publishing House, Hanoi, 411 pp.

Daxl, R., von Kayserlingk, N., Klein-Koch, C., Link, R. and Waibel, H. 1994. Integrated pest management: guidelines. Schriftenreihe der GTZ, No. 249, 119 pp.

De Faveri, S. G. and Brown, J. D. 1995. Effect of buprofezin, fluvalinate, lo-vis oil and imidachloprid against the mango scale *Aulacaspis tubercularis* (Newstead). In: R. Holmes (ed.) Mango 2000 – Proceedings of Marketing Seminar and Production Workshop. Queensland DPI, Brisbane, pp. 153-159.

de Kraker, J. 1996. The potential of natural enemies to suppress rice leaffolder populations. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 257.

DOA and DOAE (Department of Agriculture and Department of Agricultural Extension) 1995. Handbook on Mango Farm Care and Management Using Integrated Pest Management Methods. DOA-GTZ, Bangkok, Thailand, 68 pp.

Escalada, M. M. and Heong, K.L. 1993. Communication and implementation of change in crop protection. In: Crop Protection and Sustainable Agriculture. Wiley, Chisester, U.K., pp. 191-207.

Escalada, M. M. and Heong, K. L. 1997. Methods for research on farmers' knowledge, attitudes, and practices in pest management. In: K. L. Heong and M. M. Escalada (eds) Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, Philippines, pp. 1-34.

Fujisaka, S. 1990. Rainfed lowland rice: building research on farmer practice and technological knowledge. Agriculture, Ecosystems & Environment, 33, 57-74.

Fujisaka, S. 1992. Will farmer participatory research survive in the International Agricultural Research Centres? Gatekeeper Series No. SA44. IIED, London, pp. 3-14.

Golez, H. G. 1991. Bionomics and control of the mango seed borer *Noorda albizonalis* Hampson (Pyralidae, Lepidoptera). Acta Horticulturae, 291, 418-424.

Grafton-Cardwell, E. E. and Reagan, C. A. 1995. Selective use of insecticides for control of armored scale (Homoptera: Diaspididae) in San Joaquin Valley California citrus. Journal of Economic Entomology, 88, 1717-1725.

Heong, K. L. 1985. Systems Analysis in Solving Pest Management Problems. In: B. S. Lee, W. H. Loke and K. L. Heong (eds) Integrated Pest Management in Malaysia. MAPPS, Kuala Lumpur, pp. 133-149.

Heong, K. L. and Escalada, M. M. 1997a. Perception change in rice pest management: A case study of farmers' evaluation of conflict information. Journal of Applied Communication, 81, 3-17.

Heong, K. L. and Escalada, M. M. 1997b. Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, Philippines, 245 pp.

Heong, K. L. and Escalada, M. M. 1998. Changing rice farmers' pest management practices through participation in a small-scale experiment. International Journal of Pest Management, 44, 191-197.

Heong, K. L., Escalada, M. M. and Mai, V. 1994. An analysis of insecticide use in rice: case studies in the Philippines and Vietnam. International Journal of Pest Management, 40, 173-178.

Heong, K. L., Escalada, M. M., Huan, H. and Mai, V. 1998. Use of communication media in changing rice farmers' pest management in the Mekong Delta, Vietnam. Crop Protection, 17, 413-425.

Kenmore, P. E. 1991. Indonesia's Integrated Pest Management – A model for Asia. FAO Rice IPC Programme FAO, Manila.

Khoo, K. C., Ooi, P. A. C. and Ho, C. T. 1993. Crop Pests and Their Management in Malaysia. Tropical Press Sdn. Bhd., Kuala Lumpur, pp. 242.

Mai, V., Cuc, N. T. T. and Hung, N. Q. 1993. Farmers' perceptions of rice pest problems and management tactics used in Vietnam. International Rice Research News, 18, 31.

Mai, V., Huan, N. H., Heong, K. L., Escalada, M. M. and Lazaro, A. A. 1997. Rice farmers' pest management perceptions and practices in Long An province, Vietnam. In: K. L. Heong and M. M. Escalada (eds) Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, pp. 215-226.

Matteson, P. C. 1996. Implementing IPM: policy and institutional revolution. Journal of Agricultural Entomology, 13, 173-183.

Mengech, A. N., Saxena, K. N. and Gopalan, H. N. B. 1995. Integrated Pest Management in the Tropics. John Wiley and Sons, West Sussex, pp. 171.

Morse, S. and Buhler, W. 1997. Integrated pest management: Ideals and Realities in Developing Countries. Lynne Riener Publishers, London, 171 pp.

Nathaniels, N. 1998. Self help, cashew trees, and learning in rural primary schools, Nachingwea District, Tanzania. In Workshop Proceedings IPM Communications and Information Workshop for Eastern and Southern Africa (ICWESA) (Nairobi: International Centre for Insect Physiology and Ecology (ICIPE)), pp. 142-147.

Nayman, O. 1990. State of organizational activities among fruit growers: potential for self-help. In: Proceedings of the Technical Conference IPM in Selected Fruit Trees. Department of Agricultural Extension, Chiang Mai, pp. 135-146.

Normiyah, R. and Chang, P. M. 1997. Pest management practices of rice farmers in the Muda and Kemubu irrigation schemes in Peninsular Malaysia. In: K. L. Heong and M. M. Escalada (eds) Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, pp. 115-127.

Norton, G. A. 1993. Philosophy, Concepts and Techniques. In: G. A. Norton and J. D. Mumford (eds) Decision Tools for Pest Management. CAB International, Wallingford, pp. 1-21.

Ochou, G. O., Matthews, G. A. and Mumford, J. D. 1998. Farmers' knowledge and perception of cotton insect pest problems in Cote d'Ivoire. International Journal of Pest Management, 44, 5-9.

Othman, Y. and Suranant, S. 1995. The Production of Economic Fruits in South-East Asia. Oxford University Press, New York, 419 pp.

PCARRD (Philippines Council for Agriculture, Forestry and Natural Resources Research and Development) 1994. The Philippines Recommends for Mango. PCARRD, Los Baños, pp. 124.

Pollard, G. V. 1991. Constraints to IPM development and a strategy for management of tomato and cabbage pests in Trinidad, West Indies. Tropical Pest Management, 37, 59-62.

Raheja, A. K. 1995. Practice of IPM in South and Southeast Asia. In: Mengech, A. N., Saxena, K. N. and Gopalan, H. N. B. (eds) Integrated Pest Management in the Tropics. John Wiley and Sons, West Sussex, pp. 69-119.

Schwab, A. 1995. Pesticides – aid to agriculture or poison – and the conflicting role of the development worker. In: R. Altenburger (ed.) Pesticides in Tropical Agriculture. Margraf Verlag, Weikersheim, pp. 107-147.

Stock, T. 1996. Group activities for participatory monitoring and evaluation: an adaptable model. Journal of Extension Systems, 12, 33-44.

Teng, P. S. 1987. The Systems Approach to Pest Management. In: P. S. Teng (ed.) Crop Loss Assessment and Pest Management. APS Press, St. Paul, Minnesota, pp. 160-167.

Tjornhom, J. D., Norton, G. W., Heong, K. L., Talekar, N. S. and Gapud, V. P. 1997. Determinants of pesticide misuse in Philippine onion production. Philippine Entomologist, 11, 139-149.

Trutmann, P., Voss, J. and Fairhead, J. 1993. Management of common bean diseases by farmers in the Central African Highlands. International Journal of Pest Management, 39, 334-342.

Trutmann, P., Voss, J. and Fairhead, J. 1996. Local knowledge and farmer perceptions of bean diseases in the Central African Highlands. Agriculture and Human Values, 13, 64-70.

van de Fliert, E. 1993. Integrated Pest Management: Farmer Field Schools Generate Sustainable Practices. A Case Study in Central Java Evaluating IPM Training. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 404.

van Huis, A. and Meerman, F. 1997. Can we make IPM work for resource-poor farmers in sub-Saharan Africa? International Journal of Pest Management, 43, 313-320.

van Huis, A., Nauta, R. S. and Vulto, M. E. 1982. Traditional pest management in maize in Nicaragua: a survey. Mededelingen Landbouwhogeschool Wageningen, 82-6, 43 pp.

Van Mele, P. 1998. Status of IPM in fruit trees in SE Asia. In: P. Van Mele and N. V. Huynh (eds) Proceedings of the First Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management. Cantho University, Can Tho, Vietnam, pp. 42-49. (in Vietnamese).

Van Mele, P. and Hai, T. V. 1999. Pesticide Use in Orchards in the Mekong Delta of Vietnam. In: Proceedings of the 5th International Conference on Plant Protection in the Tropics, Kuala Lumpur, March 15-18th, 1999, pp. 529-533.

Waage, J. 1998. Sustainable pest management in smallholder tree crops: farmers as IPM experts. Internal report CABI Bioscience/Global IPM Facility, pp. 5.

Waibel, H. 1986. The Economics of Integrated Pest Control in Irrigated Rice. A Case Study from the Philippines. Springer-Verlag, Berlin, pp. 196.

Waite, G. K. 1998. Integrated pest management in tropical and subtropical fruits in Queensland. In: Proceedings of the International Conference of IPM, Guangzhou, China, p. 135.

Waterhouse, D. F. 1998. Biological Control of Insect Pests: Southeast Asian Prospects. ACIAR, Canberra, 548 pp.

Youm, O. and Baidu-Forson, J. 1995. Farmers' perception of insect pests and control strategies, and their relevance to IPM in pearl millet. In: K. F. Nwanze and O. Youm (eds) Panicle Insect Pests of Sorghum and Pearl Millet: Proceedings of an International Consultative Workshop. ICRISAT, Patencheru, India, pp. 291-296.

3. Farmers' perceptions and practices in use of *Dolichoderus thoracicus* (Smith) (Hymenoptera: Formicidae) for biological control of pests of sapodilla

Abstract

In 1996, a majority (61%) of 190 sapodilla farmers in the Mekong Delta, Vietnam, considered the black ant *Dolichoderus thoracicus* (Smith) as beneficial in decreasing damage by the fruit borer *Alophia* sp. (51%), the mealybug *Planococcus lilacinus* (Cockerell) (43%) and 'bad' ants notably *Cardiocondyla wroughtoni* (Forel) (38%). A significant greater proportion of orchards in Can Tho had *D. thoracicus* (60%) than in Tra Vinh (42%) ($P<0.05$). In orchards where *D. thoracicus* were present, 25% fewer farmers sprayed insecticides than farmers without *D. thoracicus*. Promoting greater farmers' acceptance of *D. thoracicus* may be difficult, because 30% of the farmers said that *D. thoracicus* increases mealybug populations. The influence of *D. thoracicus* on both *Alophia* sp. and *P. lilacinus* infestations was tested in both provinces, in 1996 and 1997. The mealybug *P. lilacinus* was not affected, but *Alophia* sp. populations were significantly smaller in ant-abundant trees ($P<0.01$). In Tra Vinh, the use of high-pressure pumps to spray tree canopies with water hampered *D. thoracicus* and lessened *Alophia* sp. control. Farmer-to-farmer training and mass media campaigns about the beneficial effect of *D. thoracicus* should be conducted to promote wider use of this ant species as a biological control agent and to reduce pesticide use in sapodilla orchards.

Introduction

Traditional farming systems often include components which can be used to develop more intensive crop production systems (Altieri, 1993). Farmers have much indigenous technical knowledge about their crop environment, but sometimes misunderstand it (Bentley *et al.*, 1994). Scientists could build upon those components that are compatible with scientific knowledge (Farrington, 1988; Scoones and Thompson, 1994). However, traditional knowledge may rapidly disappear, for example because farmers have increasingly moved to the use of chemical products (Chapter 4).

In some traditional farming systems, farmers were the first to recognize and encourage the beneficial role of some ant species (Gotwald, 1986) notably seven genera of dominant ant species – *Oecophylla*, *Dolichoderus*, *Anoplolepis*, *Wasmannia*, and *Azteca* in the tropics, *Solenopsis* in the tropics and subtropics, and *Formica* in temperate environments (Way and Khoo, 1992). Ants may therefore be useful in pest management, but positive attributes must be weighed against possible disadvantages, as some ants benefit pest Homoptera, and attack or irritate humans, domestic animals and other useful animals (Buckley and Gullan, 1991; Way and Khoo, 1992). In the Mekong Delta of Vietnam, farmers have a long tradition of ant husbandry in citrus using the weaver ant *Oecophylla smaragdina* Fabricius (Hymenoptera: Formicidae) (Barzman *et al.*, 1996; Chapter 4). In China, *O. smaragdina* has been used since the third century AD as a biological control agent in citrus and is still being used as such (Huang and Yang, 1987). Based on this traditional knowledge and after extensive, scientific studies (Peng *et al.*, 1995; 1997; 1998), *O. smaragdina* has been successfully used in commercial cashew plantations in Australia.

The black ant *D. thoracicus* has been reported to suppress populations of different pests of perennial crops (Khoo and Ho, 1992; Way and Khoo, 1992; CABI, 1998), in particular cocoa. So far, *D. thoracicus* has not been used as a biological control agent in fruit crops, mainly because the ants also attend mealybugs (Way and Khoo, 1992). Sapodilla (*Manilkara zapota* (L.) P. van Royen), a member of the Sapotaceae family, is widely cultivated in the tropics, including SE Asia. In the Mekong Delta, Vietnam, it is the fourth most important perennial fruit crop, with a total production area of 3,700 ha (Chau, 1998). Surveys indicated the fruit borer *Alophia* sp. (Lepidoptera: Pyralidae), the twig borer *Pachyteria equestris* Newman (Coleoptera: Cerambycidae) and the mealybug *Planococcus lilacinus* (Cockerell) (Homoptera: Pseudococcidae) as the major pest species (Cuc, unpublished data). In particular *Alophia* sp. was reported to decrease yields by 30-60% in Vietnam and at least 60% in the Philippines (Coronel, 1994). Earlier surveys conducted in the Mekong Delta showed that some farmers utilized *D. thoracicus* mainly to suppress *Alophia* sp. (Cuc, unpublished data).

Lack of information on current farmers' knowledge, perceptions and practices is a major constraint in developing and establishing an integrated pest management (IPM) programme (this thesis; Matteson *et al.*, 1984; Morse and Buhler, 1997). Fixed prescriptions (IPM packages) do not work, since site-specific agro-ecological and socio-economic conditions determine what is best in each location (van Huis and Meerman, 1997). Therefore, a survey was conducted in two different provinces in order to (i) evaluate the presence of *D. thoracicus* in sapodilla orchards, (ii) examine the farmers' attitudes to *D. thoracicus* and (iii) make an inventory of ant husbandry techniques. Using this information, experiments were conducted to study the role of *D. thoracicus* in controlling the sapodilla fruit borer *Alophia* sp. and the influence of ant attendance on the infestation level of the mealybug *P. lilacinus*.

Materials and methods

Farmers' knowledge, perception and practices related to* D. thoracicus *in sapodilla

From June to September 1996, 90 sapodilla farmers were interviewed in Can Tho Province, and 100 in Tra Vinh Province. Selection of Provinces and districts was based on production area, differences in climate and agricultural practices. Can Tho Province is in the centre of the Mekong Delta and has an average annual rainfall of 1700 mm. Tra Vinh is on the East Coast of the Mekong Delta and has 1300 mm of rainfall per year. The dry season lasts from November to May.

A ridge cultivation system, with raised beds on which several rows of sapodilla trees are grown, is most common in both locations. During the dry season, in Can Tho, irrigation water is pumped from the canals onto the planting beds, whereas in Tra Vinh, about 80% of the farmers use high-pressure pumps to spray canopies with water. This practice has been widely promoted by the Extension Service as a way to control insect pests.

Sapodilla orchards were selected based on the following criteria: (i) orchard size (> 0.2 ha), (ii) years under production (> 3 years), and (iii) willingness of the farmer to be interviewed. Staff members of the Plant Protection Department, Cantho University conducted the survey. Interviews about the presence and husbandry of *D. thoracicus* and farmers' appraisal were followed by a cross-checking visit to the orchard. Survey data were analyzed using the SPSS statistical package. Results of the survey are presented as the percentage of farmers responding affirmatively to each of the interview questions. The Pearson correlation coefficient was calculated to test for independence between variables. Relevant farmers' comments and practices concerning ant husbandry were recorded and are presented here as unquantified statements.

Influence of D. thoracicus on Alophia sp. and P. lilacinus

Six on-farm experiments were carried out in the two Provinces, to study the effect of *D. thoracicus* on the degree of infestation level by *Alophia* sp. and *P. lilacinus*. In Tra Vinh Province, experiments were conducted from September 1996 to July 1997, and in Can Tho from December 1996 to September 1997. In each Province, 3 orchards were selected which were known to have well established ant colonies. All orchards had 6 to 8 year old trees, which were planted at a density of 220-250 trees/ha in a monocrop system. Within and around the orchards, non-crop vegetation such as banana plants was more abundant in Can Tho Province.

Exclusion techniques were used to evaluate the effect of foraging ants on *Alophia* sp. and *P. lilacinus* pest populations. In each orchard, two experimental blocks, one with and one without ants, were established and isolated by canals. In the ant-excluded block, trees before flowering were sprayed with esfenvalerate (Sumi-alpha 5EC) to kill the ants and sources of contamination by ants were removed. Contamination sources consisted of ant nests in plant debris, in cut bamboo poles laying on the ground, and in young, un-opened leaf sheaths of banana plants and spadices of *Nypa fruticans* Wurmb. (Palmae), which typically grows along orchard canals. Ant presence in the other block was kept up to about 200 ants per tree per two minute counts. Additional colonies were introduced from other orchards if necessary. This level of abundance was defined as moderate according to the scoring method of Way and Khoo (1991).

In each experimental orchard, five randomly selected trees with ants were compared with five randomly selected trees without ants. About 40 randomly selected fruits per tree were sampled weekly. Damage by *Alophia* sp. was sampled from four weeks after fruit set (WAF) to harvest time and was expressed as percentage of fruits damaged. The damage can easily be observed by the insect frass and the drips of solidified white latex coming from the point where larvae have entered the fruit. Sampling of *P. lilacinus* started at 9 WAF in Can Tho and 12 WAF in Tra Vinh Province and lasted until harvest time. Two different approaches were used. In Can Tho, *P. lilacinus* infestation was expressed as percentage of fruits infested, an infested fruit being one which carried at least one adult female or at least four larvae. In Tra Vinh, *P. lilacinus* infestation was low and therefore the number of mealybugs were counted, without distinguishing between adults and larvae. Data of number of mealybugs were transformed to log(x+1). Data from ant-excluded and ant-abundant trees were compared using t-tests.

Results

Status of D. thoracicus *in sapodilla*

About 90% of the sapodilla orchards in Tra Vinh Province were younger than 10 years, whereas in Can Tho, more than 90% of the orchards were older than 10 years (Table 1). Most of the orchards were smaller than 0.5 ha. A significant greater proportion of orchards in Can Tho had *D. thoracicus* (60%) than in Tra Vinh (42%) (Pearson χ^2=6.14, P<0.05). In both provinces, about 20% of those farmers with *D. thoracicus* in their orchard practiced ant husbandry.

Table 1. Percentage of sapodilla farmers having orchards of different age and size in two provinces, Mekong Delta, Vietnam, 1996.

	% farmers	
	Can Tho	Tra Vinh
	n=90	*n*=100
Age orchard (years)		
4-<6	0.0	55.0
6-<8	2.3	23.0
8-<10	3.4	11.0
>10	94.3	11.0
Size orchard (ha)		
<0.5	93.1	62.0
≥ 0.5	6.9	38.0

Farmers' ant husbandry practices

Farmers made a ball of dried banana leaves or grasses and placed them in the fork of a main branch of a tree to establish *D. thoracicus*. This was a preferred nesting place for the ants. Many farmers also interplanted their orchards with bananas. Young, un-opened leaf sheaths of banana plants proved to be ideal, more stable nesting places, especially during the rainy season. To provide *D. thoracicus* with extra food in the dry season, or to stimulate distribution of ants in their orchard, farmers poured a sugar solution over the plant residues around the trees.

***Farmers' perception of* D. thoracicus**

Farmers' perception of the role of *D. thoracicus* in sapodilla orchards was significantly different between the two provinces (P<0.001) (Table 2). The majority (70%) in Can Tho Province attributed a positive role to *D. thoracicus*, but 30% mentioned that the ant would increase populations of the mealybug *P. lilacinus*. In Tra Vinh, 18% of the farmers had no opinion about the role of *D. thoracicus*. Only a few farmers mentioned this ant as a nuisance when fruits had to be harvested.

Table 2. Percentage of farmers considering *Dolichoderus thoracicus* as beneficial in sapodilla orchards, Mekong Delta, Vietnam, 1996.

Beneficial role of *D. thoracicus*	% farmers	
	Can Tho	Tra Vinh
Yes	70.0	52.0
No	30.0	30.0
Indifferent	0.0	18.0

χ^2=18.74, P<0.001, df=2.

Dolichoderus thoracicus was considered to be beneficial in decreasing damage by the fruit borer *Alophia* sp. (51%), the mealybug *Planococcus lilacinus* (Cockerell) (43%) and 'bad' ants notably *Cardiocondyla wroughtoni* (Forel) (38%). These ants were reported to be closely associated with scale insects and mealybugs, and had no apparent beneficial role in sapodilla orchards. Furthermore, they rapidly colonize orchards where *D. thoracicus* are absent. Therefore, many sapodilla farmers preferred *D. thoracicus* in their orchard, even though they did not always actively take care of them. Fifty percent of the farmers also attributed improved fruit appearance to the presence of ants: a smoother skin increasing the market value.

Farmers' perception of major sapodilla pests

The fruit borer *Alophia* sp. was most frequently mentioned by sapodilla farmers in both Provinces, followed by twig borers (Coleoptera: Cerambycidae) (Table 3). *Alophia* sp. was targeted for spraying by 37% of the farmers in Can Tho and by 59% in Tra Vinh Province. However, the most important spray target according to 86% of the farmers in Tra Vinh were leaf-feeding caterpillars (Lepidoptera: Pyralidae), which were targeted on average 10 times per year (range 2-30). About 70% of the farmers used monocrotophos (Azodrin) and 32% used methamidofos (Monitor), both products being lethal to *D. thoracicus*. Although leaf-feeding caterpillars can be found in Can Tho, only 10% of the farmers mentioned it as a pest problem and sprayed against it. Generally, farmers in Can Tho applied monocrotophos (20%) and diazinon (10%).

Table 3. Percentage of farmers recording major pests and spray targets[1] in sapodilla orchards, Mekong Delta, Vietnam, 1996.

Province	% farmers reporting							
	Fruit borer		Mealybugs		Leaf-feeding caterpillar		Twig borers	
	Pest	Spray target	Pest	Spray target	Pest	Spray target	Pest	Spray target
Can Tho	80	37	22	29	10	10	68	16
Tra Vinh	96	59	34	10	86	86	98	2

[1] Multiple answers occurred.

D. thoracicus *and insecticide use*

In orchards where *D. thoracicus* were present, 25% fewer farmers sprayed insecticides than farmers without this ant (Table 4). In Tra Vinh, about 80% of the farmers applied insecticides in orchards with *D. thoracicus*, whereas in orchards without the ant nearly all farmers sprayed. Overall insecticide use in Can Tho Province was half of that used in Tra Vinh Province. More than 70% of the farmers in Can Tho reported that pesticides seriously affected their health. Those farmers in Can Tho who used pesticides, generally sprayed less frequently than those in Tra Vinh (Cuc, personal communication).

Table 4. Percentage of farmers using insecticide in relation to presence of *Dolichoderus thoracicus* in sapodilla orchards, Mekong Delta, 1996.

D. thoracicus	% farmers		
	Can Tho	Tra Vinh	Total
Present	41	79	57
Absent	56	98	82
$\chi 2$	1.90ns	10.51**	13.58***

ns = not significant, ** P<0.01, *** P<0.001.

Influence of D. thoracicus *on damage by* Alophia *sp.*

In Can Tho Province, the percentage of damaged fruits by *Alophia* sp. was significantly (P<0.01) reduced by *D. thoracicus* from five weeks after fruit set until harvest (Figure 1). Around harvest time, the percentage of damaged fruits was 30% for trees without and 10% for trees with *D. thoracicus*. In Tra Vinh Province, significant (P<0.01) reduction of *Alophia* sp. damage occurred only from 17 WAF onwards (Figure 2). At the end of the experiment, the percentage of damaged fruits was 55% for trees without and 32% for trees with *D. thoracicus*.

Influence of **D. thoracicus** *on* **P. lilacinus**

Nearly one-third of the farmers considered *D. thoracicus* as a pest, because it would increase *P. lilacinus* populations. On-farm experiments were conducted to test this hypothesis. In Can Tho, the influence of *D. thoracicus* on the percentage of infested fruits was tested, whereas in Tra Vinh, the influence of the ant on the population dynamics of *P. lilacinus* was investigated. Neither the experiment in Can Tho nor that in Tra Vinh, however, revealed any significant difference ($P<0.05$) in abundance of *P. lilacinus* with or without *D. thoracicus* (Figures 3 and 4).

Discussion

Status of **D. thoracicus** *in sapodilla*

Fewer sapodilla orchards have *D. thoracicus* in Tra Vinh than in Can Tho Province because of differences in environmental and agricultural factors. In Tra Vinh, non-crop vegetation, which provides *D. thoracicus* with nesting sites, is less abundant. Besides, in Tra Vinh the majority of the farmers use high-pressure pumps during the dry season to spray the tree canopies with water, destroying nests in trees and reducing ant populations. Way and Khoo (1991) described how stable nesting sites that protect *D. thoracicus* from rain are important for successful colony establishment. In Can Tho, water is bailed from the canals onto the planting beds and does not disturb arboreal nests. Besides, pesticide pressure in Can Tho is lower. Over the past few years, however, *D. thoracicus* in Can Tho has decreased due to increased insecticide use (Cuc, personal communication). A similar trend has been noticed for the weaver ant *O. smaragdina* in citrus (Chapter 4). In absence of pesticide use, orchard colonization by *D. thoracicus* often occurs naturally and populations are rather easily maintained in sapodilla as opposed to cocoa (Way and Khoo, 1991).

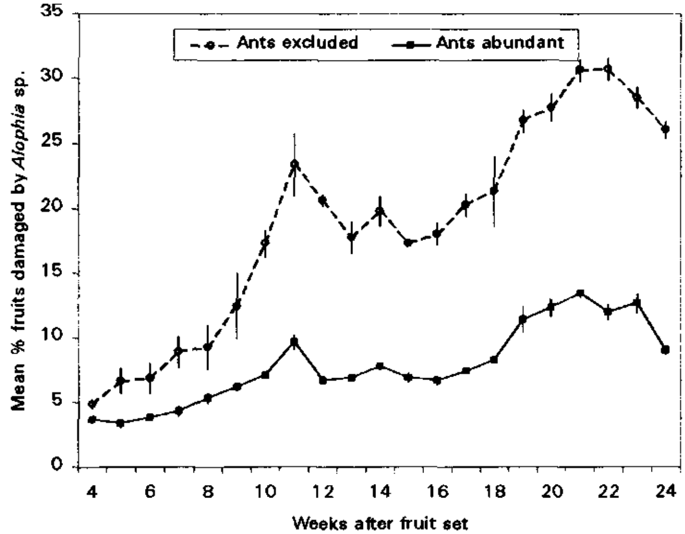

Figure 1. Mean (±SE) % of fruits damaged by *Alophia* sp. in plots with *Dolichoderus thoracicus* excluded or present in Can Tho Province, 1997.

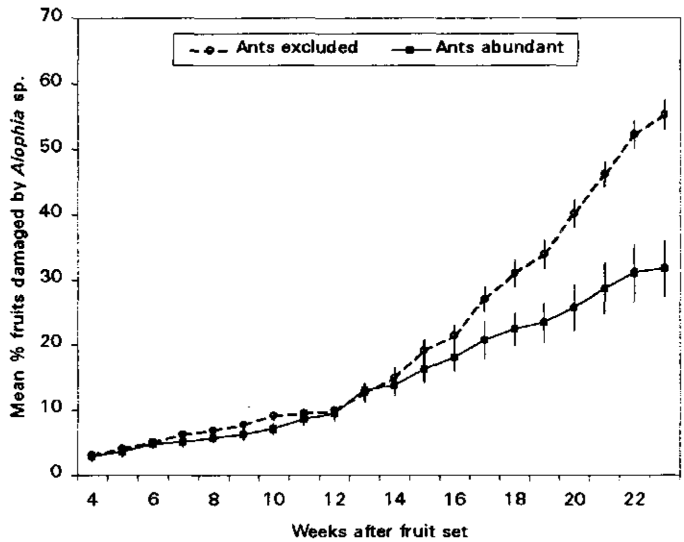

Figure 2. Mean (±SE) % of fruits damaged by *Alophia* sp. in ant-excluded and ant-present plots in Tra Vinh Province, 1997.

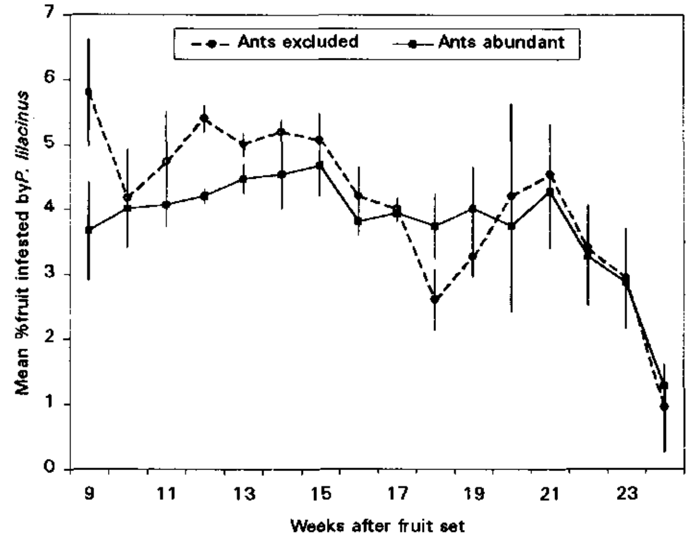

Figure 3. Mean (±SE) % of infested fruits by *Planococcus lilacinus* in ant-excluded and ant-present plots in Can Tho Province, 1997.

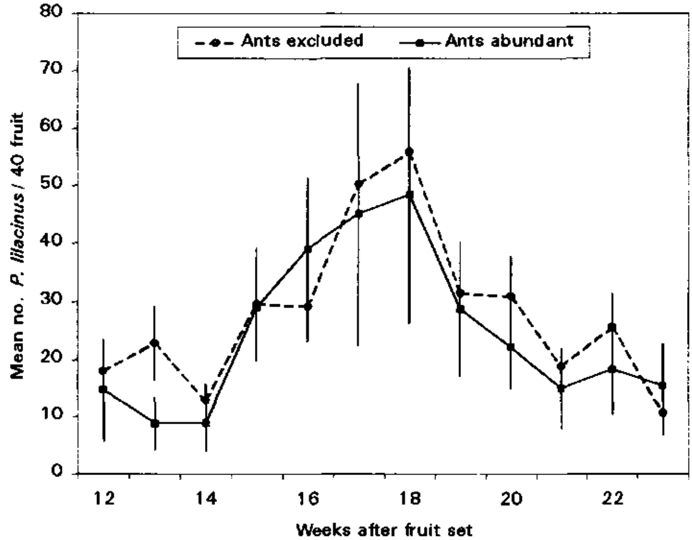

Figure 4. Mean (±SE) no. of *Planococcus lilacinus* per 40 fruits in ant-excluded and ant-present plots in Tra Vinh Province, 1997. (untransformed data).

Farmers' ant husbandry practices

Farmers suggested that the availability of banana plants as an intercrop during the first years of sapodilla orchard establishment, or as border plants during later stages increased nesting habits for *D. thoracicus*. Way and Khoo (1991) indicated that coconut trees planted around cocoa plantations provide a more stable habitat for *D. thoracicus*. Habitat diversity has also been reported to have a positive influence on colonization by *O. smaragdina* in Australian cashew plantations (Peng *et al.*, 1998) and several non-crop trees within or around citrus orchards in the Mekong Delta have been reported to host *O. smaragdina* nests (Chapter 4). The influence of non-crop vegetation, such as banana plants on *D. thoracicus* population size and distribution should be further studied.

***Farmers' perception of* D. thoracicus**

About 20% more farmers perceived *D. thoracicus* as beneficial in Can Tho than in Tra Vinh Province. This might be due to the difference in years of farmers' experience, reflected in the age of the orchard under sapodilla production. Can Tho has a long tradition of fruit cultivation, whereas in Tra Vinh, sapodilla production started only recently. Promoting broader farmers' acceptance of *D. thoracicus* establishment as a biological control agent in their orchard might prove to be difficult, as 30% of the farmers ascribed an increase in mealybug populations to the presence of the ants.

Besides the role of *D. thoracicus* in plant protection, farmers attributed a smoother skin of the fruit to the presence of ants. In citrus, *O. smaragdina* has been illustrated to improve fruit quality by increasing the shinyness and juiciness of the fruits, making the fruits more attractive for marketing (Barzman *et al.*, 1996).

Farmers' perception of major sapodilla pests

The fruit borer *Alophia* sp. was considered the most important pest by sapodilla farmers in both Provinces. Relatively fewer farmers in Can Tho, however, sprayed against this pest. The wider presence of *D. thoracicus* and the higher confidence in its beneficial role might explain this. In Tra Vinh, the most important spray target were leaf-feeding caterpillars. These are most probably a more serious pest in young orchards than in fully established trees. Similarly, in mango, where most farmers have extensive experience, leaf-feeding caterpillars were generally present, but hardly sprayed against (Chapter 2). However, caterpillars are very often sprayed once the caterpillars are well-developed, and thus after the major damage has already been done (Hill and Waller, 1988). It therefore seems appropriate to stimulate establishment of *D. thoracicus* colonies at the early stage of orchard design.

In Tra Vinh, the use of high-pressure pumps has been widely promoted by the Extension Service as a way to control insect pests. Seemingly farmers also frequently apply pesticides. These combined practices hamper *D. thoracicus* and most probably lessen pest control efficiency.

D. thoracicus *and insecticide use*

Generally, insecticides used were highly hazardous for mamals, fish and natural enemies including *D. thoracicus*. Most products belonged to WHO Toxicity Class Ib (Anonymous, 1999). In orchards where *D. thoracicus* were present, the proportion of farmers spraying insecticides was lower. Reduced insecticide use was also observed in citrus orchards when *O. smaragdina* was present (Chapter 4). A better understanding of the beneficial role of *D. thoracicus* might give farmers more confidence and reduce their insecticide use. In Malaysian cocoa plantations, commercially applied pesticides did not eliminate, but decreased *D. thoracicus* numbers, reducing crop protection efficiency by this ant (Way and Khoo, 1989). Further studies are required to evaluate the influence of type and frequency of pesticide use on population dynamics of natural enemies, such as *D. thoracicus*.

Influence of* D. thoracicus *on damage by* Alophia *sp.

Damage by *Alophia* sp. was reduced by about 20% due to the presence of *D. thoracicus*. Generally, damage was much higher in Tra Vinh than in Can Tho Province, and *D. thoracicus* was not able to reduce the damage to a low level. A stable habitat for maintenance of *D. thoracicus* colonies is very important (Way and Khoo, 1991). In Tra Vinh, surrounding non-crop vegetation was less abundant and spraying with high-pressure pumps constantly reduced ant populations. Therefore, nests had to be introduced regularly to keep the number of *D. thoracicus* up to acceptable limits. Obviously ant husbandry under such conditions becomes a much more difficult task. Farmer-to-farmer training during field sessions and mass media campaigns could be developed to change farmers' perceptions and practices related to natural enemies. This training methodology has proven to be successful in rice (Kenmore *et al.*, 1987; Heong and Escalada, 1997).

Influence of D. thoracicus on P. lilacinus

No impact of *D. thoracicus* on *P. lilacinus* was found. Since *P. lilacinus* prefers the fruit peduncle as well as the fruit, their presence and the presence of associated sooty moulds affect the cosmetic appearance of fruit and therefore reduce their market value. In cocoa, a close mutualistic relationship exists between *D. thoracicus* and the mealybug *Cataenococcus hispidus* (Morrison) (Homoptera: Pseudococcidae) (Khoo and Ho, 1992; Ho and Khoo, 1997). Although these mealybugs feed by sucking sap from the pod peduncle, pod, and other parts of the cocoa tree, yield is not affected (Khoo and Chung, 1989). At what level mealybugs cause economical damage in sapodilla still has to be investigated, though problems with cosmetic appearance are definitely greater than for cocoa. Some authors suggested that ants attending mealybugs keep away natural enemies of the mealybugs and that therefore *D. thoracicus* in fruit trees are unwanted and should be controlled (Khoo and Chung, 1989; Khoo *et al.*, 1993). However, mean percentage of fruits infested by *P. lilacinus* in Can Tho and mean number of adults and larvae per fruit in Tra Vinh remained low.

D. thoracicus played an important role in the transport of mealybugs between cocoa pods (Ho and Khoo, 1997). However, in none of our experiments did we observe an increase in *P. lilacinus* population or the number of fruits infested by *P. lilacinus* due to ant attendance. Mealybug transport does not occur until the ant population has reached a certain level of abundance, a level which was probably not reached during our experiments (Khoo, personal communication).

References

Altieri, M. A. 1993. Designing and improving pest management systems for subsistence farmers. In: M. A. Altieri (ed.) Crop Protection Strategies for Subsistence Farmers. Westview Press, Boulder, Colorado, pp. 1-44.

Anonymous 1999. Database on pesticides and the environment. Economic and Social Commission for Asia and the Pacific (ESCAP), Centre de co-opération Internationale en Recherche Agronomique pour le Développement (CIRAD), Commission of the European Union (EU). http://www.fadinap.com/pesticide.

Barzman, M. S., Mills, N. J. and Cuc, N. T. T. 1996. Traditional knowledge and rationale for weaver ant husbandry in the Mekong Delta of Vietnam. Agriculture and Human Values, 13(4), 2-9.

Bentley, J. W., Rodriguez, G. and Rodriguez, A. 1994. Science and people: Honduran campesinos and natural pest control inventions. Agriculture and Human Values, 11, 178-182.

Buckley, R. and Gullan, P. 1991. More aggressive ant species (Hymenoptera: Formicidae) provide better protection for soft scales and mealybugs (Homoptera: Coccidae, Pseudococcidae). Biotropica, 23, 282-286.

CABI 1998. 'Crop Protection Compendium – CDRom Module 1'. CAB International, Wallingford.

Coronel, R. E. 1994. Promising fruit of the Philippines. University of the Philippines, Los Baños, pp. 508.

Chau, N. M. 1998. Evaluation of the potential of fruit trees in the Mekong Delta: prospect in domestic and export consumption. In: Commercialization of Tropical Fruits in South

Vietnam. Workshop Proceedings Southern Fruit Research Institute, Long Dinh, June 12-13, 1998, pp. 54-65.
Southern Fruit Research Institute, Long Dinh.

Farrington, J. 1988. The role of indigenous technical knowledge. In: J. Farrington and A. Martin (eds) Farmer Participation in Agricultural Research. Overseas Development Insitute, pp. 23-29.

Gotwald, W. H. 1986. The beneficial economic role of ants. In: S. B. Vinson (ed.) Economic Impact and Control of Social Insects. Praeger, New York, pp. 290-313.

Heong, K. L. and Escalada, M. M. 1997. Perception change in rice pest management: A case study of farmers' evaluation of conflict information. Journal of Applied Communication, 81, 3-17.

Hill, D. S. and Waller, J. M. 1988. Pests and Diseases of Tropical Crops. Vol. 2. Longman Scientific and Technical, New York, pp. 432

Ho, C. T. and Khoo, K. C. 1997. Partners in biological control of cocoa pests: mutualism between *Dolichoderus thoracicus* (Hymenoptera: Formicidae) and *Cataenococcus hispidus* (Hemiptera: Pseudococcidae). Bulletin of Entomological Research, 87, 461-470.

Huang, H. T. and Yang, P. 1987. The ancient cultured citrus ant. Bioscience, 37, 665-671.

Kenmore, P. E., Litsinger, J. A., Bandong, J. P., Santiago, A. C. and Salac, M. M. 1987. Philippine rice farmers and insecticides: thirty years of growing dependancy and new options for change. In: J. Tait and B. Napompeth (eds) Management of Pests and Pesticides. Farmers' Perceptions and Practices. Westview Press, Boulder, Colorado, pp. 98-108.

Khoo, K. C. and Chung, G. F. 1989. Use of black cocoa ant to control mirid damage in cocoa. The Planter, 65, 370-383.

Khoo, K. C. and Ho, C. T. 1992. The influence of *Dolichoderus thoracicus* (Hymenoptera: Formicidae) on losses due to *Helopeltis theivora* (Heteroptera: Miridae), black pod disease, and mamalian pests in cocoa in Malaysia. Bulletin of Entomological Research, 82, 485-491.

Khoo, K. C., Ooi, P. A. C. and Ho, C. T. 1993. Crop Pests and Their Management in Malaysia. Tropical Press Sdn. Bhd., Kuala Lumpur, pp. 242.

Matteson, P. C., Altieri, M. A., and Gagné, W. C. 1984. Modification of small farmer practices for better pest management. Annual Review of Entomology, 29, 383-402.

Morse, S. and Buhler, W. 1997. Integrated pest management: Ideals and Realities in Developing Countries. Lynne Riener Publishers, London, 171 pp.

Peng, R. K., Christian, K. and Gibb, K. 1995. The effect of the green ant *Oecophylla smaragdina* (Hymenoptera: Formicidae), on insect pests of cashew trees in Australia. Bulletin of Entomological Research, 85, 279-284.

Peng, R. K., Christian, K. and Gibb, K. 1997. Control threshold analysis for the tea mosquito bug, *Helopeltis pernicialis* (Hemiptera: Miridae) and preliminary results concerning the efficiency of control by the green ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae) in northern Australia. International Journal of Pest Management, 43, 233-237.

Peng, R. K., Christian, K. and Gibb, K. 1998. The effect of non-crop vegetation on the insect pests and their natural enemies in cashew (*Anacardium occidentale* L.) plantations. Plant Protection Quarterly, 13, 16-20.

Scoones, I. and Thompson, J. 1994. Knowledge, power and agriculture – towards a theoretical understanding. In: I. Scoones and J. Thompson (eds) Beyond Farmer First – Rural People's Knowledge, Agricultural Research and Extension Practice. Intermediate Technology Publications, London, pp. 16-32.

van Huis, A. and Meerman, F. 1997. Can we make IPM work for resource-poor farmers in sub-Saharan Africa? International Journal of Pest Management, 43, 313-320.

Way, M. J. and Khoo, K. C. 1989. Relationships between *Helopeltis theobromae* damage and ants with special reference to Malaysian cocoa smallholdings. Journal of Plant Protection in the Tropics, 6, 1-11.

Way, M. J. and Khoo, K. C. 1991. Colony dispersion and nesting habits of the ants, *Dolichoderus thoracicus* and *Oecophylla smaragdina* (Hymenoptera: Formicidae) in relation to their success as biological control agents on cocoa. Bulletin of Entomological Research, 81, 341-350.

Way, M. J. and Khoo, K. C. 1992. Role of ants in pest management. Annual Review of Entomology, 37, 479-503.

4. Evolution and status of *Oecophylla smaragdina* (Fabricius) as a pest control agent in citrus in the Mekong Delta

Abstract

Citrus farmers in the Mekong Delta have a long tradition of managing the weaver ant *Oecophylla smaragdina* (Fabricius). From 1994 to 1998, insecticide use increased significantly ($P<0.01$) from 66% to 84% in orchards where *O. smaragdina* occurred. In 1998, *ca* 75% of the sweet orange (*Citrus sinensis*) and 25% of the Tieu mandarin (*C. reticulata*) orchards had large *O. smaragdina* populations, due to a lower pesticide pressure in the first crop. In orchards with *O. smaragdina*, farmers sprayed less frequently and used fewer insecticides that are highly hazardous. Major insecticides used in sweet orange were monocrotophos and alpha-cypermethrin, and those used in Tieu mandarin were methidathion, imidacloprid and fenpropathrin. Expenditure on pesticides was reduced by half when *O. smaragdina* was abundant, without affecting either the yield or the farmers' income. Therefore, *O. smaragdina* husbandry is a good example of a traditional practice which should be further promoted as an important component of sustainable citrus production. The experience of those farmers that use no or few pesticide should be drawn upon in developing farmer training programmes or mass media tools to promote IPM in citrus. Farmers practicing ant husbandry were significantly ($P<0.01$) older than those not doing so.

Introduction

Citrus is the major fruit crop in the Mekong Delta, Vietnam, being cultivated over an area of 38,000 ha (DAFF, 1996). The main citrus species grown are sweet orange (*Citrus sinensis* (L.) Osbeck), Tieu mandarin, sweet mandarin (*C. reticulata* Blanco) and pummelo (*C. maxima* (Burm.) Merr.), whereas lime trees (*C. aurantiifolia* (Christm.) Swingle) are often found around orchards. Orchards are generally small, with one family cultivating *ca* 0.5 ha. On average, about 1,000 trees/ha are planted on raised beds, separated by canals. The weaver ant, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae), is traditionally used by citrus farmers in the Mekong Delta, mainly for reasons of improvement of fruit quality. Experiments indicated that external shine and fruit juiciness were improved when ants were present. It was suggested that ant wastes are nutrients for the plant, altering the physiology of individual developing fruit (Barzman *et al.*, 1996).

The highly organized aggressive predatory behaviour of *O. smaragdina*, combined with extensive foraging throughout the area occupied by a colony, explains its success in killing or driving away many pests or potential pests. This has been illustrated for heteropteran, lepidopteran and leaf-feeding coleopteran pests in citrus, mango, litchi, coconut and cashew (Huang and Yang, 1987; Way and Khoo, 1992; Khoo *et al.*, 1993; Peng *et al.*, 1995). However, weaver ant aggression has been an obstacle for its use in many parts of the world, mainly in plantations, and therefore *Oecophylla* ants have often been considered a pest (Way and Khoo, 1992).

In the Mekong Delta, the main insect pests targeted by sweet orange farmers were the citrus leafminer *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae), the aphids *Toxoptera aurantii* (Boyer de Fonscolombe) and *T. citricidus* (Kirkaldy) (Homoptera: Aphididae), and the citrus stinkbug *Rhynchocoris humeralis* (Thnb.) (Heteroptera: Pentatomidae). In Tieu mandarin, the main pests targeted were the citrus leafminer, mites, including the citrus red mite *Panonychus citri* (Mc Gregor) (Acarina: Tetranychidae) and the citrus rust mite *Phyllocoptruta oleivora* Ashmead (Acarina: Eriophyidae), and to a lesser extent mealybugs (Homoptera: Pseudococcidae) (Chapter 5). The psyllid *Diaphorina citri* (Kuwayama) (Homoptera: Psyllidae), vector of the citrus greening disease was mostly not targeted by citrus farmers. The noctuid fruit-piercing moths *Eudocima salaminia* (Cramer), *Ophiusa coronata* (Fabricius) and *Othreis* spp. have been previously reported to occur in about 20% of the citrus orchards (Cuc *et al.*, 1998). The citrus flower moth *Prays citri* Millière (Lepidoptera: Yponomeutidae) and the fruit flies *Bactrocera* spp. (Diptera: Tephritidae) occur less frequently.

In some preliminary experiments, *Oecophylla smaragdina* effectively controlled the citrus stinkbug, larvae of *Papilio* spp. (Lepidoptera: Papilionidae), aphids and citrus leafminer (Barzman, Mills and Cuc, unpublished). The citrus greening disease was very low to completely absent in orchards with abundant ants, compared to orchards without ants. The vector *D. citri* was rarely observed in orchards with *O. smaragdina*. In laboratory experiments, the egg stage of *D. citri* was heavily preyed upon, reducing populations of *D. citri* by more than 60% (Cuc, unpublished). Sweet orange farmers generally perceived lower infestation rates of all major pests, except for mealybugs, when weaver ants were present (Chapter 5).

As traditional farming systems are prone to many external forces, of which the pesticide industry is but one, it is imperative to assess current farmers' knowledge (Farrington, 1988; Morse and Buhler, 1997). As rural people have extensive knowledge of relatively conspicuous organisms such as social insects, scientists can learn much from them (Bentley, 1992). The traditional use of an endemic ant species as a successful biological control agent therefore deserves special attention. Eroding indigenous technological knowledge (ITK), however, is often the case where: (i) the importance of the cash economy becomes so great that farmers seek to maximize yield, and (ii) where human population growth has exceeded the rate at which ITK can enhance the carrying capacity of land (Farrington, 1988). Both of these conditions are prevalent in the Mekong Delta, Vietnam, thus endangering the traditional practice of weaver ant husbandry. To restore confidence and dynamism in ITK systems, external support may be necessary. Scientific validation by local and foreign scientists may increase farmers' pride in the use of traditional knowledge (Thrupp, 1989). It could also help to define which farmers could be integrated as experts in future IPM training programmes.

In this chapter, the evolution and status of *O. smaragdina* in citrus orchards is discussed in relation to pesticide use, habitat biodiversity and cropping system. An economical assessment of sweet orange and Tieu mandarin production systems is included related to ant abundance.

Materials and methods

From 1994 to 1998 two surveys were conducted in order to assess the status of *O. smaragdina* in citrus orchards in the Mekong Delta. In 1994, 250 farmers and in 1998, 150 farmers were interviewed in Can Tho and Dong Thap Province. The important citrus trees cultivated were sweet orange (*C. sinensis*) and Tieu mandarin (*C. reticulata*). Sampling was stratified according to production area of the respective citrus species. Within each stratum, farmers were randomly selected. Sweet orange is mainly restricted to Can Tho Province and was sampled in Can Tho City, Chau Thanh and Omon District. Tieu mandarin is very susceptible to flooding (*Fusarium solani* root rot) and therefore is mainly grown in those areas with a slightly higher elevation, on soils which allow better drainage. Sampling for Tieu mandarin was consequently carried out in Omon District of Can Tho Province and in Lai Vung District, Dong Thap Province.

The questionnaires aimed to assess socio-economic, agronomic and pest management aspects. A combination of structured and semi-structured open questions was used. Farmers' ITK related to *O. smaragdina* and pest control received special emphasis. The content of the questionnaire and type of questions asked was agreed upon after key informant interviews. Questions included farmers' assessment of pest infestation and damage, the actual pests treated for (Chapter 5), the type and frequency of pesticide used, and some economic enquiries such as the annual yield and expenditure for agrochemicals. The questionnaire was pre-tested and revised. On average, each questionnaire took 2-3 h of interview with each farmer. Staff of the Plant Protection Department, Cantho University, conducted the surveys. Both parametric and non-parametric statistics were used to analyse data and details of the specific tests are indicated within the text or below the tables. Information from field observations such as the type of cropping system and suitability of non-crop trees as nesting sites for *O. smaragdina* is presented as unquantified statements.

Results

Weaver ant husbandry practices

Some ant colonies are merely tolerated, but the majority are actively cared for, justifying the name of ant husbandry (Barzman *et al.*, 1996). Husbandry of *O. smaragdina* involves obtaining and establishing ant colonies, providing food and refuge for the ants, placing bridges between trees and protecting established colonies from competing ant species. It also involves avoiding pesticide use as much as possible.

Some farmers control the weaver ant prior to harvest, as they experience them as an obstacle. Therefore, about 30% of the farmers engaged in weaver ant husbandry applied insecticides around harvest time to control the ants.

Obtaining and establishing *O. smaragdina* colonies is becoming an increasing problem. To obtain a colony, farmers used to collect 20 to 30 nests from one colony in the natural vegetation and place these in their orchard. Due to increased land pressure, natural vegetation has become more scarce, reducing the possibility of collecting nests in their natural habitat. Nests from established colonies in one orchard may be introduced to others. Obtaining a few nests, however, is not a guarantee for successful colony establishment. Ants often migrate and populations usually drastically decrease within 2 months after being introduced. According to some farmers, the best period for establishing new colonies is the end of the rainy season (November-December), when many nests contain big larvae which are probably queens. Farmers observed this change in size of the larvae as they are used as fishing bait. At this time, farmers protect their nests from being stolen.

Food, such as fish or chicken intestines, is sometimes provided to the ants by placing it directly on a branch of one of the citrus trees. Farmers connect trees by bamboo poles or nylon strings, providing ants with aerial bridges and thus fascilitating the movement and distribution of ants within the orchard.

Competing ant species, such as the black ant, *Dolichoderus thoracicus* Smith were reported to hinder colonization by *O. smaragdina* in citrus orchards and are therefore regarded as a pest. Farmers make artificial nests, such as a ball of dried leaves or grasses, as a trap. After establishment of the black ant colony, they collect the nests and burn them. Many citrus farmers spray insecticides to control *D. thoracicus*.

In 1998, abundant *O. smaragdina* were encountered in 65% of the orchards that were 10 years and older (n=46), compared to 44% in the more recently established orchards (n=104) (Pearson χ^2=5.62, P<0.05). Farmers practicing ant husbandry were significantly older, 55 years old compared to 45 years (Student t=4.59, P<0.01). Educational level of the farmer had no influence on the practice of ant husbandry.

Evolution of insecticide use and weaver ant status

In absence of *O. smaragdina* nearly all farmers sprayed insecticides (Table 1). Farmers who had *O. smaragdina* in their orchard, used significantly fewer insecticide in both years, about 30% fewer in 1994 and about 15% fewer in 1998. The majority (88%) of the latter group was concentrated in Can Tho Province. Ant husbandry was most popular in Can Tho Province, where in 1998, 46% of the citrus farmers practiced this, compared to only 15% in Dong Thap Province.

Table 1. Evolution of insecticide use in citrus in relation to presence of *O. smaragdina*, Mekong Delta.

O. smaragdina	% farmers using insecticides		% increase	χ2
	1994 *n=250*	1998 *n=150*		
Present	66.1	83.5	17.4	9.94**
Absent	97.1	98.1	1.0	ns
χ2	16.62***	7.28**		

ns = not significant, * P<0.05, ** P<0.01, *** P<0.001.

From 1994 to 1998, a major increase was observed in the use of methidathion, being strongly promoted on TV commercials for use against mites, mealybugs and scales. Other products with acaricidal activity such as fenpropathrin, sulphur, hexythiazox and propargite were also commonly used in 1998 (Table 2). All these pesticides were applied on Tieu mandarin only. In sweet orange, the use of pyrethroids such as alpha-cypermethrin increased, mainly to target citrus leafminer and leaf rollers (Lepidoptera: Tortricidae). The total number of active ingredients used on citrus increased from 16 to 37. On average 1.0 active ingredient was used per farm in 1994 compared to 2.6 different chemicals in 1998. Nearly all products are harmful to *O. smaragdina* and other beneficial organisms.

Orchard biodiversity and weaver ant abundance

Twenty six percent of the orchards were under mixed cropping, and had significantly (Pearson χ^2=17.51, P<0.001) more abundant *O. smaragdina* populations. Annual intercropping, mainly with banana, was less than 10%. About 15% of the farmers integrated animal production, mainly fish cultivation in the canals of their orchard. This was irrespective of the presence of *O. smaragdina*. With the exception of a few products such as imidacloprid and sulphur, nearly all products are toxic to fish. Non-crop vegetation within or closely surrounding the orchard often contained *O. smaragdina* nests. Characteristics of these plants are given in Table 3.

Major citrus cropping systems and pesticide use in relation to weaver ant abundance

Majority of the citrus cropping systems had abundant *O. smaragdina* populations, except for orchards with Tieu mandarin. About 10% of the orchards of Tieu mandarin were mixed, compared to about 50% for sweet orange (Table 4). Seventy five percent of the orchards with sweet orange and about 25% of orchards with Tieu mandarin had abundant ant populations. The abundance in sweet orange was similar within all three districts in Can Tho Province. Similarly, distribution of *O. smaragdina* in Tieu mandarin was irrespective of the location sampled.

Both in sweet orange and Tieu mandarin orchards, farmers used fewer pesticides when *O. smaragdina* was abundant (Table 5). Pesticide use in sweet orange was generally low. In Tieu mandarin, insecticides were applied as many as 7.4 times per year in orchards with abundant *O. smaragdina* populations, compared to 13.9 in orchards without. Fungicides were applied as many as 4.8 times per year, compared to 9.8 with or without high ant populations.

Table 2. Major insecticides and acaricides used in citrus in 1994 and 1998, Mekong Delta.

Insecticide/acaricide	WHO Classification[1]	% farmers	
		1994	1998
Organophosphates			
Methyl parathion	Ia	20.9	13.3
Monocrotophos	Ib	25.9	22.7
Methamidophos	Ib	10.1	11.3
Methidathion	Ib	-	30.7
Diazinon	II	7.9	5.3
Dimethoate	II	1.1	6.0
Carbamates			
Carbofuran	II	6.1	10.0
BPMC	Ib	2.2	11.3
Methomyl	Ib	-	4.0
Pyrethroids			
Deltamethrin	II	10.1	10.7
Cypermethrin	II	5.0	9.3
Alpha-cypermethrin	II	-	18.0
Fenpropathrin	II	-	12.7
Lambda-cyhalothrin	II	-	4.7
Esfenvalerate	II	1.1	8.7
Fenvalerate	II	1.1	3.3
Others			
Imidacloprid	II	-	10.7
Sulphur	IV	-	9.3
Fenvalerate + Dimethoate	-	-	8.0
Propargite	III	-	8.0
Ethofenprox	IV	2.2	7.3
Fenpyroximate	-	-	7.3
Hexythiazox	IV	-	6.0

[1] Ia = extremely hazardous, Ib = highly hazardous, II = moderately hazardous, III = slightly hazardous, IV = unlikely to present acute hazard in normal use, - = unclassified. Source: Anonymous, 1999; multiple answers occurred.

Table 3. Characteristics of non-citrus trees, which act as refuge for *O. smaragdina* in citrus orchards in the Mekong Delta.

Scientific name	Local name	Location	Other uses	Remarks
Eucalyptus tereticornis L.	Tram vang	Border	Wood Medicinal oil	Is said to reduce soil fertility Mainly grown on poor soil
Ceiba pentandra (L.) Gaertn.	Gon	Border	Wood Kapok for pillows Leaves for incense	Often solitary trees Sparse canopy
Mangifera indica L.	Xoai	Border Intercrop Home garden	Fruit	Often on dikes between orchard and paddy field Crop of economic importance and therefore sprayed with insecticides
Spondias dulcis Soland. ex Park.	Coc	Intercrop	Fruit	Tree with few pests Never sprayed Sparse canopy Ideal plant as refuge
Annona glabra L.	Cach	Canal	Fruit Against soil erosion	Planted or native
Premna integrifolia Roxb.	Binh-bat nuoc	Canal Home garden	Young leaves as vegetables	Planted or native

Table 4. Percentage of orchards within different citrus cropping systems in relation to abundance of *O. smaragdina*, Mekong Delta, 1998.

	TM[1]	SO	SM	KO	SO+SM	SO+KO	SO+TM	KO+SM	Other
No. of orchards	75	28	6	2	17	8	5	5	4
O. smaragdina									
Abundant	25	71	100	0	76	100	40	100	75
Not abundant	75	29	0	100	24	0	60	0	25

[1] TM=Tieu mandarin (*C. reticulata*), SO=sweet orange (*C. sinensis*), SM=sweet mandarin (*C. reticulata*), KO=king orange (*C. nobilis*), Other=citrus mixed with other fruit crop.

The total number of different active ingredients of insecticides used was 18 in sweet orange and 35 in Tieu mandarin. With abundant *O. smaragdina* populations, farmers used fewer insecticides that are highly hazardous to humans (Table 6). However, irrespective of ant abundance, the most frequently used products all had broad-spectrum control activity and were classified by the World Health Organization (WHO) as highly (category Ib) to moderately (category II) hazardous.

Table 5. Pesticide use in sweet orange (*C. sinensis*) and Tieu mandarin (*C. reticulata*) in relation to abundance of *O. smaragdina*, Mekong Delta, 1998.

	Sweet orange		Tieu mandarin	
	ants abundant *n*=42	ants not abundant *n*=12	ants abundant *n*=21	ants not abundant *n*=57
Insecticides/acaricides				
No. of products used	1.4±1.4^{a}	2.5±1.7^{b}	2.6±1.8^{b}	4.0±1.7^{c}
No. of sprays	3.1±3.3^{a}	4.3±3.1^{a}	7.4±6.2^{a}	13.9±8.6^{b}
Farmers using carpet sprays (%)	76.2	100.0	76.2	96.5
Farmers not using (%)	21.4	0.0	9.5	1.8
Fungicides				
No. of products used	0.8±1.4^{a}	1.5±1.6^{ab}	2.4±1.9^{bc}	3.0±2.0^{c}
No. of sprays	1.3±2.1^{a}	1.8±2.1^{a}	4.8±5.3^{a}	9.8±8.0^{b}
Farmers not using (%)	57.1	33.3	14.3	8.8

[a,b,c] Different letters following mean ± SD within rows indicate significant differences at the 5% level (LSD, ANOVA).

Pesticide selection criteria and sources of information

The knock-down effect of the pesticide was the most important criterion, mentioned by about 70% of all the citrus farmers. This was irrespective of *O. smaragdina* abundance in Tieu mandarin. In sweet orange, about half of the farmers with abundant ant populations compared to all of the farmers without mentioned this criterion. Familiarity with the product was the second most important criteria. Availability of the product was described as important by 21% of the sweet orange farmers with abundant ants in their orchard, but never mentioned by any of the other farmers.

Sixty percent of the farmers relied on their own experience when purchasing a particular product, whereas about 40% were influenced by media. Thirty percent of the sweet orange farmers said the pesticide seller was an important source of information, whereas 22% of Tieu mandarin farmers said asking advice from the extension officer.

Economical assessment related to weaver ant husbandry

Using the Student's t-test, neither yield nor net income, as reported by the farmer, was influenced by *O. smaragdina* (Table 7). Average yield of both citrus crops ranged between 21 and 25 tonnes per ha per year. Expenditure data were compared with the Mann-Whitney U-test. Both in sweet orange and in Tieu mandarin, the average insecticide and fungicide expenditure was less when *O. smaragdina* was abundant.

Discussion

Weaver ant husbandry practices

The aggressive behaviour of *O. smaragdina* to humans has been an obstacle, and therefore this ant has often been considered a pest (Way and Khoo, 1992). During a survey in the Mekong Delta in 1993, ant aggression was not identified as a problem by citrus farmers (n=43) (Barzman *et al.*, 1996). In 1998, about one-third of those farmers with high ant populations sprayed insecticides around harvest time to prevent *O. smaragdina* from being a hindrance during fruit picking. Alternative ways of reducing hindrance, such as moving ant nests or luring ants to non-crop trees outside the orchard, should be developed within an IPM programme.

Table 6. Percentage farmers[1] using different types of insecticides and acaricides in sweet orange (*C. sinensis*) and Tieu mandarin (*C. reticulata*) in relation to abundance of *O. smaragdina*, Mekong Delta, 1998.

Insecticide/acaricide	WHO Toxicity Class[2]	Sweet orange		Tieu mandarin	
		ants abundant	ants not abundant	ants abundant	ants not abundant
Organophosphates					
Methyl parathion	Ia	14.3	25.0	9.5	14.0
Monocrotophos	Ib	26.2	58.3	14.3	13.0
Methamidophos	Ib	4.8	33.3	9.5	15.8
Methidathion	Ib	7.1	8.3	28.6	59.6
Diazinon	II	7.1	8.3	9.5	1.8
Dimethoate	II	0.0	0.0	0.0	15.8
Carbamates					
Carbofuran	II	9.5	0.0	9.5	15.8
Fenobucarb (BPMC)	Ib	7.1	8.3	4.8	21.1
Methomyl	Ib	0.0	0.0	4.8	8.8
Pyrethroids					
Deltamethrin	II	7.1	8.3	9.5	8.8
Cypermethrin	II	0.0	0.0	4.8	21.1
Alpha-cypermethrin	II	21.4	41.7	9.5	14.0
Fenpropathrin	II	0.0	0.0	19.0	22.8
Lambda-cyhalothrin	II	0.0	0.0	4.8	8.8
Esfenvalerate	II	0.0	16.7	19.0	12.3
Fenvalerate	II	0.0	0.0	4.8	5.3
Others					
Imidacloprid	II	0.0	0.0	19.0	35.1
Sulphur	IV	0.0	0.0	19.0	17.5
Fenvalerate + Dimethoate	-	0.0	0.0	9.5	14.0
Propargite	III	0.0	0.0	9.5	17.5
Ethofenprox	IV	11.9	16.7	0.0	5.3
Fenpyroximate	-	0.0	0.0	4.8	17.5
Hexythiazox	IV	0.0	0.0	14.3	14.0

[1] calculated for all orchards except for those 5 cases where both species were cultivated together, multiple answers occurred.
[2] Ia = extremely hazardous, Ib = highly hazardous, II = moderately hazardous, III = slightly hazardous, IV = unlikely to present acute hazard in normal use, - = unclassified. Source: Anonymous, 1999;

Table 7. Some economical characteristics of sweet orange (*C. sinensis*) and Tieu mandarin (*C. reticulata*) production in relation to abundance of *O. smaragdina*, Mekong Delta, 1998.

	Sweet orange		Tieu mandarin	
	ants abundant	ants not abundant	ants abundant	ants not abundant
Yield (tonnes/ha/year)	21.2[a]	24.3[a]	23.1[a]	23.7[a]
Expenditure insecticides (U$/ha/year)	26.6[a]	56.3[b]	103.3[a]	208.3[b]
Expenditure fungicides (U$/ha/year)	11.7[a]	47.4[b]	152.0[a]	287.4[b]
Expenditure chemical fertilizer (U$/ha/year)	44.6[a]	106.2[a]	299.6[a]	384.3[a]
Net income (U$/ha/year)	2,435.4[a]	2,204.7[a]	5,365.3[a]	4,939.3[a]

[a,b] Different letters within rows within the same crop indicate significant differences at the 10% level.

Weaver ant husbandry involves a wide array of techniques such as colony establishment and controlling competing ants. In cashew plantations in northern Australia, introduction of partial colonies was more permanent with a reproductive queen than without a queen (Peng *et al.*, 1998b). Establishment of new colonies often fails because in each colony, the queens apparently remain in one nest only and they are not replaceable (Peng *et al.*, 1998a). In Vietnam, the black ant *D. thoracicus* is commonly used as a biological control agent in sapodilla (Chapter 3). As this ant competes with *O. smaragdina*, sapodilla is never interplanted with citrus or vice versa. In citrus, banana plants containing nests of *D. thoracicus* should be removed.

Whether farmers had a high or low level of education did not influence ant husbandry practice, but farmers practising ant husbandry were generally older. These farmers should be used as valuable resource persons in the development of a citrus IPM programme.

Evolution of insecticide use and weaver ant status

From 1994 to 1998, insecticide use increased, with double the number of active ingredients influenced by the interest of chemical companies and the readiness of farmers (Van Mele and Hai, 1999). Barzman *et al.* (1996) warned that increased pressure upon farmers to use agrochemicals would probably result in the disappearance of the weaver ant from citrus, as in China in the 1970s (Huang and Yang, 1987). This further stresses the urgent need to promote farmers, mainly those in Can Tho Province, as experts in training programmes for IPM in citrus for Vietnam and eventually other SE Asian countries interested in sustainable citrus production. Scientific validation may increase farmers' pride in the use of traditional knowledge (Thrupp, 1989). Farmers should be made aware that using biological control agents is more 'modern' than using chemicals, and that increased insecticide application does not equate with increased profits (Kenmore *et al.*, 1987).

Orchard biodiversity and weaver ant abundance

Although no quantitative data were collected, we observed many *O. smaragdina* nests in non-crop vegetation within or closely surrounding the orchard. These nests might be of utmost importance for the surviving of a colony when pesticides are applied and for recolonization of the orchard between successive pesticide applications. Close proximity of non-crop vegetation was an important factor influencing dispersal of *O. smaragdina* in cashew orchards in northern Australia (Peng *et al.*, 1998a) and in coconut plantations in the Solomon Islands (Greenslade, 1971).

In the Mekong Delta, *O. smaragdina* nests are often located in small trees such as *Annona glabra* L. (Annonaceae), which grow along the canals between the planting beds, or in taller trees such as *Spondias dulcis* Soland. Ex Park. and *Mangifera indica* L. (Anacardiaceae), which traditionally provide fruits and shade as an intercrop in many citrus orchards. Given their physical position within the orchard, they offer good potential for recolonization of *O. smaragdina*. Way and Khoo (1991) suggested that besides providing better nesting sites, interplanted non-crop trees provide a diverse and dependable source of food from honeydew-producing Homoptera. The presence of non-crop trees might explain why still so many citrus orchards have ant colonies, despite the increasing use of insecticides. Due to increased land pressure in the Mekong Delta and the government policy stimulating conversion of mixed orchards to monocrops, the availability of non-crop vegetation within and around orchards is continuously decreasing. This trend might endanger the survival of ant colonies and the practice of weaver ant husbandry in the near future.

Major citrus cropping systems and pesticide use in relation to weaver ant abundance

The high pesticide pressure might explain why *O. smaragdina* was less abundant in Tieu mandarin, compared to other citrus crops. Barzman *et al.* (1996) likewise reported that mandarin orchards often lack a permanent colony of ants, and that ants are regularly introduced at the stage immediately following fruit set. This practice might become more and more difficult as the natural vegetation in these intensively cropped agricultural areas is diminishing.

Number of insecticide and fungicide sprays in Tieu mandarin was 50% less in orchards with abundant *O. smaragdina* populations. Growing consumer awareness of pesticide residues, after reported incidences of acute poisonings, might provide an extra marketing advantage to Tieu mandarins cultivated with weaver ants in the near future.

Spotless and shiny Tieu mandarin fruits obtain a very high price as they are harvested around Tet, the Vietnamese new year (February). For offerings to the ancestors, this fruit with an orange-red colour is preferred over other citrus fruits. To avoid damage to the skin of the fruit by mites and thrips, farmers frequently applied methidathion, fenpropathrin, propargite and sulphur. Farmers should proceed with caution as in many countries, the excessive use of synthetic pesticides in tree fruit crops has lead to pest resistance (Huang and Yang, 1987), a decrease in natural enemies and increased problems with scales, mites and mealybugs (Waite, 1998).

Availability of IPM-friendly alternatives for farmers are very important. In Vietnam, petroleum spray oils (PSO) have been registered for use only since 1999. It is important to investigate how selective products can be best integrated with the use of weaver ant husbandry, and what impacts ants have on other natural enemies.

Sources of information

Farmers' own experience, the media and the pesticide seller were the most important sources of information for purchasing a particular product. In Tieu mandarin, extension service had a more important role than in sweet orange. This is due to regional differences. Dong Thap, with a high acreage of fruit crops in general and Tieu mandarin in particular, has a strong extension service focusing on fruit crops. Farmers concentrate their efforts on their orchard and are eager for new information and products.

The Farmer Field School approach in rice in which farmers are helped in understanding biological control through a process of learning by experimenting and discovery in the field (Kenmore *et al.*, 1987; van de Fliert, 1993; Ooi, 1996), offers some useful ideas for IPM programmes in fruit crops. The media could be used in promoting IPM principles, as it has been proven successful in changing rice farmers' pest management in the Mekong Delta (Heong *et al.*, 1998). In particular the experience of those citrus farmers that use no or few pesticide should be drawn upon in developing mass media tools and/or farmer training programmes.

Economical assessment related to weaver ant husbandry

When *O. smaragdina* was abundant, less farmers used leaf fertilizers. Farmers attributed improved fruit quality to the presence of the weaver ant, and compared the 'ant urine' with fertilizers (Barzman *et al.*, 1996). They considered NPK fertilizer as a possible, albeit less desirable, substitute for the weaver ant. Mean expenditure for insecticides and fungicides was about 50% lower when *O. smaragdina* was abundant. Despite the lower input of agrochemicals in orchards with ants, average yields did not decrease. In China, yield of oranges under biological control with *O. smaragdina* was as good as under chemical control (Huang and Yang, 1987).

Therefore, the use of *O. smaragdina* in citrus, both as a fruit quality improver as well as a biological control agent, offers benefits in terms of a better environment, less health risks for farmers and consumers, without affecting farmers' income. *O. smaragdina* husbandry should be promoted in both sweet orange and Tieu mandarin production.

References

Anonymous 1999. Database on pesticides and the environment. Economic and Social Commission for Asia and the Pacific (ESCAP), Centre de co-opération Internationale en Recherche Agronomique pour le Développement (CIRAD), Commission of the European Union (EU). http://www.fadinap.com/pesticide.

Barzman, M. S., Mills, N. J. and Cuc, N. T. T. 1996. Traditional knowledge and rationale for weaver ant husbandry in the Mekong Delta of Vietnam. Agriculture and Human Values, 13(4), 2-9.

Bentley, J. W. 1992. The epistemology of plant protection: Honduran campesino knowledge of pests and natural enemies. In: R. W. Gibson and A. Sweetmore (eds) Proceedings of a Seminar on Crop Protection for Resource-Poor Farmers. CTA/NRI, pp. 107-118.

Cuc, N. T. T., Hung, N. V. and Dien, L. Q. 1998. Insect pests on citrus, durian, longan and mango in selected provinces of the Mekong Delta of Vietnam. In: P. Van Mele and N. V. Huynh (eds) Proceedings of the First Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management. Cantho University, Can Tho, Vietnam, pp. 71-76. (in Vietnamese).

DAFF (Department of Agriculture, Forestry and Fishery) 1996. Statistical Data of Agriculture, Forestry and Fishery 1985-1995. Statistical Publishing House, Hanoi, 411 pp.

Farrington, J. 1988. The role of indigenous technical knowledge. In: J. Farrington and A. Martin (eds) Farmer Participation in Agricultural Research. Overseas Development Insitute, pp. 23-29.

Greenslade, P. J. M. 1971. Interspecific competition and frequency changes among ants in Solomon Islands coconut plantations. Journal of Applied Ecology, 8, 323-349.

Heong, K. L., Escalada, M. M., Huan, H. and Mai, V. 1998. Use of Communication media in changing rice farmers' pest management in the Mekong Delta, Vietnam. Crop Protection, 17, 413-425.

Huang, H. T. and Yang, P. 1987. The ancient cultured citrus ant. Bioscience, 37, 665-671.

Kenmore, P. E., Litsinger, J. A., Bandong, J. P., Santiago, A. C. and Salac, M. M. 1987. Philippine rice farmers and insecticides: thirty years of growing dependancy and new options for change. In: J. Tait and B. Napompeth (eds) Management of Pests and Pesticides. Farmers' Perceptions and Practices. Westview Press, Boulder, Colorado, pp. 98-108.

Khoo, K. C., Ooi, P. A. C. and Ho, C. T. 1993. Crop Pests and Their Management in Malaysia. Tropical Press Sdn. Bhd., Kuala Lumpur, pp. 242.

Morse, S. and Buhler, W. 1997. Integrated pest management: Ideals and Realities in Developing Countries. Lynne Riener Publishers, London, 171 pp.

Ooi, P. A. C. 1996. Experiences in educating rice farmers to understand biological control. Entomophaga, 41, 375-385.

Peng, R. K., Christian, K. and Gibb, K. 1995. The effect of the green ant *Oecophylla smaragdina* (Hymenoptera: Formicidae), on insect pests of cashew trees in Australia. Bulletin of Entomological Research, 85, 279-284.

Peng, R. K., Christian, K. and Gibb, K. 1998a. How many queens are there in mature colonies of the green ant, *Oecophylla smaragdina* (Fabricius)? Australian Journal of Entomology, 37, 249-253.

Peng, R. K., Christian, K. and Gibb, K. 1998b. The effect of non-crop vegetation on the insect pests and their natural enemies in cashew (*Anacardium occidentale* L.) plantations. Plant Protection Quarterly, 13, 16-20.

Thrupp, L. A. 1989. Legitimizing local knowledge: from displacement to empowerment for third world people. Agriculture and Human Values, 6(3), 13-24.

van de Fliert, E. 1993. Integrated Pest Management: Farmer Field Schools Generate Sustainable Practices. A Case Study in Central Java Evaluating IPM Training. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 404.

Van Mele, P. and Hai, T. V. 1999. Pesticide Use in Orchards in the Mekong Delta of Vietnam. In: Proceedings of the 5th International Conference on Plant Protection in the Tropics, Kuala Lumpur, March 15-18th, 1999, pp. 529-533.

Waite, G. K. 1998. Integrated pest management in tropical and subtropical fruits in Queensland. In: Proceedings of the International Conference of IPM. Guangzhou, China, p. 135.

Way, M. J. and Khoo, K. C. 1989. Relationships between *Helopeltis theobromae* damage and ants with special reference to Malaysian cocoa smallholdings. Journal of Plant Protection in the Tropics, 6, 1-11.

Way, M. J. and Khoo, K. C. 1991. Colony dispersion and nesting habits of the ants, *Dolichoderus thoracicus* and *Oecophylla smaragdina* (Hymenoptera: Formicidae) in relation to their success as biological control agents on cocoa. Bulletin of Entomological Research, 81, 341-350.

Way, M. J. and Khoo, K. C. 1992. Role of ants in pest management. Annual Review of Entomology, 37, 479-503.

5. Direct and indirect influences of the weaver ant *Oecophylla smaragdina* on citrus farmers' pest perceptions and management practices

Abstract

In the Mekong Delta, Vietnam, the predatory weaver ant *Oecophylla smaragdina* was abundant in about 75% of the sweet orange and 25% of the Tieu mandarin orchards. With a three-level scale (low, moderate and high) farmers assessed incidence, severity and yield loss of fruit caused by major pests. With abundant *O. smaragdina*, sweet orange farmers assessed lower pest infestation or yield loss for citrus stinkbug *Rhynchocoris humeralis*, aphids *Toxoptera aurantii* and *T. citricidus*, leaf-feeding caterpillars *Papilio* spp. and inflorescence eaters. In Tieu mandarin, use of agrochemicals was higher than in sweet orange and pest risk assessment was not correlated with ant abundance, except for aphid infestation, which was rated lower. Number of sprays targeting a particular pest was positively correlated both with pest incidence and severity and negatively correlated with ant abundance. Irrespective of *O. smaragdina* abundance, citrus leafminer *Phyllocnistis citrella* was one of the major spray targets. Citrus red mite *Panonychus citri* was the most important target in Tieu mandarin, accounting for more than 30% of all target sprays. Stimulating *O. smaragdina* as a biological control agent in Tieu mandarin will only be successful when mites can be controlled simultaneously without excessive chemical treatments. The concept of ant predation, well known by most farmers, could be used as a starting point to educate farmers about the existence and role of predatory mites.

Introduction

Over the past decade, scientists have increasingly emphasized conservation biological control enhancing endemic natural enemies, as a means of sustainable pest management in orchards (Liang and Huang, 1994; Gurr *et al.*, 1998; Pickett and Bugg, 1998). Traditional farming systems are often regarded as economically unsustainable. However, these systems have 'man-made ecological sustainability' (Zadoks, 1993), whereas 'modern' farming systems in many cases are ecologically unsustainable (Gurr *et al.*, 1998). That traditional systems are economically unsustainable should not be generalized.

Citrus farmers in the Mekong Delta, Vietnam have a long tradition of managing the weaver ant *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae) (Barzman *et al.*, 1996; Chapter 4). Farmers' pride in the use of traditional knowledge and practices could be increased if they are scientifically validated (Thrupp, 1989; Barzman *et al.*, 1996; Olkowski and Zhang, 1998). Chemical pest control in developing countries is too often considered the only way ahead towards 'modern' pest management (Matteson *et al.*, 1984). However, biological control with *O. smaragdina* is not restricted to small-scale, traditional farming systems as it currently plays a key role in reducing the incidence of the main insect pests in commercial cashew plantations in northern Australia (Peng *et al.*, 1995). Cashew yields and nut quality were even higher when trees were protected with *O. smaragdina* compared to chemical crop protection, making biological control in this crop not only ecologically, but also economically more sustainable (Peng *et al.*, 1999).

Preliminary experiments in the Mekong Delta indicated that some of the main citrus pests such as the stinkbug *Rhynchocoris humeralis* (Thnb.) (Heteroptera: Pentatomidae), the aphids *Toxoptera aurantii* (Boyer de Fonscolombe) and *T. citricidus* (Kirkaldy) (Homoptera: Aphididae), the leafminer *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) and several other lepidopteran species could be controlled by *O. smaragdina* (Barzman, Mills and Cuc, unpublished). Even though ants such as *O. smaragdina* and *Dolichoderus thoracicus* (Smith) (Hymenoptera: Formicidae) have often been reported to tend honeydew-producing Homoptera, *Oecophylla* has never been associated with outbreaks of these pests (Way, 1963; Huang and Yang, 1987; Löhr, 1992).

To identify research priorities and improve the design and effectiveness of training programmes, it is important to study farmers' knowledge, perceptions and practices (Farrington, 1988; Fujisaka, 1990; Morse and Buhler, 1997). We discuss citrus farmers' use of agrochemicals, their assessment of insect pest incidence, severity and yield loss, and how differences could directly or indirectly be attributed to the presence of *O. smaragdina*. Based on these findings, recommendations for curriculum development for IPM research and training programmes are formulated.

Materials and methods

In 1998, 132 citrus farmers, cultivating sweet orange or Tieu mandarin as their major crop, were interviewed in Can Tho and Dong Thap Province, Mekong Delta, Vietnam. Sampling was stratified according to production area of the respective citrus species. Within each stratum, farmers were randomly selected based on a list held by the Service of Agriculture and Rural Development. One criterion was that orchards had to be at least four years old. Sweet orange is mainly restricted to Can Tho Province and was sampled in Can Tho City, Chau Thanh and Omon District. Tieu mandarin is very susceptible to flooding and therefore is mainly grown in those areas with a slightly higher elevation and on soils that allow better drainage. Sampling for Tieu mandarin was consequently carried out in Omon District of Can Tho Province and in Lai Vung District, Dong Thap Province.

The content of the questionnaire and type of questions asked was agreed upon after key informant interviews. The questionnaire was pretested and revised. On average, each questionnaire took 2-3 hours of interview with each farmer. People involved in the survey were members of the Plant Protection Department, Cantho University. The questionnaire was aimed at getting a clear picture of the agro-ecosystem, the farmers' pest risk assessment and the pest management they carried out. A combination of structured and semi-structured open questions was used. Farmers' knowledge, perceptions and practices related to pests and to *O. smaragdina* husbandry received special emphasis. Farmers were first asked to record the most important pest problems. For each of the major pests, pest incidence, pest severity and estimated yield loss were ranked on a 3-level scale (low, moderate and high). Pest incidence was explained to the farmer as the proportion of the orchard infested and pest severity as the degree of attack on infested plants only. In cases where pesticides were used, farmers were asked to specify which products they used, how many times they sprayed and which pests were targeted. Target sprays were calculated as the sum of the number of sprays for each product applied against a pest. The relative importance farmers attribute to a pest was calculated as the number of target sprays against a pest divided by the total sum of target sprays against all pests.

Survey data were encoded and analysed with SPSS statistical software. Both sweet orange and Tieu mandarin orchards were divided into two groups: with or without abundant populations of *O. smaragdina*. Populations were defined as abundant in case ants were observed foraging in most of the trees. Both parametric and non-parametric tests were used and are indicated throughout the text. Degrees of freedom are one, unless stated otherwise. Logistic regressions were conducted to investigate whether ant abundance determined whether specific pesticide products were used. Regression models were routinely calculated starting with all independant variables. At each step the variable with the highest P value was omitted until only significant variables remained in the model (Agresti, 1990). An odds ratio (O.R.) smaller than one indicates that the product was used by fewer farmers when ants were abundant.

Results

Citrus farmers' profile

Oecophylla smaragdina was more abundant in sweet orange (78%) than in Tieu mandarin (27%) orchards. In orchards with abundant ant populations farmers practiced weaver ant husbandry to some extent (Chapter 4), partly by avoiding pesticide sprays as much as possible and by avoiding to spray the nests in the trees. Weaver ant husbandry was generally practiced by older sweet orange (P=0.08) and Tieu mandarin (P<0.01) farmers (Table 1). About 40% of them were older than 60 years. There was no difference in education level and access to extension courses between farmers with and without ants. Irrespective of ant abundance, more farmers had attended extension courses in Dong Thap than in Can Tho Province (χ^2=20.32, P<0.01). Trees were older in Tieu mandarin orchards with abundant *O. smaragdina* compared to those without. About 50% of the sweet orange orchards were mixed cropping systems, whereas Tieu mandarin orchards were generally all under monocrop (χ^2=36.53, P<0.001). Nearly all orchards were smaller than 1 ha.

Table 1. Profile of farmers (mean±SE) cultivating sweet orange (*C. sinensis*) and Tieu mandarin (*C. reticulata*) with and without abundant *Oecophylla smaragdina* populations in their citrus crop, Mekong Delta, Vietnam, 1998.

	Sweet orange		Tieu mandarin	
	ants abundant *n*=42	ants not abundant *n*=12	ants abundant *n*=21	ants not abundant *n*=57
Age farmer (years)	54.9±2.2[a]	46.8±3.5[a]	55.9±2.6[a]	46.3±1.5[c]
Education (no. of years of school)	6.8±0.6[a]	7.6±0.8[a]	8.2±0.8[a]	7.0±0.5[a]
Extension courses (%)	16.7[a]	7.1[a]	26.3[a]	23.8[a]
Age trees (years)	8.9±0.9[a]	6.9±1.0[a]	9.7±1.2[a]	7.0±0.5[b]
Orchard size (ha)	0.7±0.1[a]	0.5±0.1[a]	0.5±0.1[a]	0.6±0.1[a]
Mixed perennial crops (%)	52.4[a]	33.3[a]	9.5[a]	1.8[a]

[a,b,c] *Different letters indicate significant differences at the 5% and 1% level based on Student's t-test* (numerical data) or Pearson χ^2-test (%).

Major insect pests and diseases

Citrus leafminer *P. citrella* was the most frequently (about 90%) mentioned insect pest, followed by the citrus stinkbug *R. humeralis* (about 80%). Aphids, including *Toxoptera aurantii* and *T. citricidus* (Homoptera: Aphididae), were more frequently mentioned by sweet orange farmers (80%) than by Tieu mandarin farmers (35%) (Pearson χ^2=25.96, P<0.001). Sweet orange farmers also mentioned more leaf-feeding caterpillars *Papilio* spp. (Lepidoptera: Papilionidae) (χ^2=9.31, P<0.01), inflorescence eaters (Lepidoptera: Pyralidae) (χ^2=12.08, P<0.01), leafrollers (Lepidoptera: Tortricidae) (χ^2=27.30, P<0.001) and branch borers (unidentified) (χ^2=22.34, P<0.001). Only sweet orange growers mentioned citrus psyllids *Diaphorina citri* (Kuwayama) (Homoptera: Psyllidae), vector of the citrus greening disease (CGD). CGD is caused by the bacteria *Liberobacter asiaticum* and spread by the psyllid *D. citri*. It is also spread by uncontrolled vegetative propagation. All of the citrus trees were vegetatively propagated and produced by the farmers themselves or purchased from small-scale commercial nurseries without the necessary infrastructure to produce CGD-free plantlets.

Farmers' knowledge of difficult-to-observe pests can be mainly attributed to extension activities, which focused on the CGD in Can Tho (Chapter 6). Only Tieu mandarin farmers in Dong Thap reported thrips, *Thrips* sp. and *Scirtothrips* sp. (Thysanoptera). Besides, they also mentioned the citrus red mite *Panonychus citri* (Mc Gregor) (Acarina: Tetranychidae) more frequently (χ^2=24.11, P<0.01) than Tieu mandarin farmers in Can Tho. Extension activities in Dong Thap focused both on mites and thrips (Chapter 6). Mealybugs (Homoptera: Pseudococcidae) (χ^2=5.76, P<0.05) and scales (Homoptera: Coccidae, Diaspididae) (χ^2=3.97, P=0.05) were also reported more by Tieu mandarin farmers in Dong Thap than in Can Tho.

Aphids and leaf-feeding caterpillars in sweet orange, and mealybugs in Tieu mandarin were reported less frequently when *O. smaragdina* was abundant (Table 2). However, in the latter crop, more inflorescence eaters were reported in orchards with *O. smaragdina*. Termites (Isoptera) and other unidentified ant species were typically mentioned as pests by about 15% of the farmers practicing weaver ant husbandry.

The yellow leaf syndrom, mainly indicating the CGD, was reported by about 90% of the sweet orange farmers and 70% of the Tieu mandarin farmers in Can Tho, whereas only 30% of the farmers in Dong Thap mentioned this disease. Citrus black spot, *Guignardia citricarpa* Kiely, and citrus canker, caused by the bacteria *Xanthomonas campestris* pv. *citri* (Hasse) Dye, were common problems in both citrus crops, being reported by about 50-60%

of the farmers. In Tieu mandarin, root rot caused by *Fusarium solani* Martius Sacc. was the most serious problem. It is most severe from October to January, at the end of the flooding season. Compared to sweet orange, Tieu mandarin is more susceptible to root rot and therefore often planted on slightly more elevated soils. More and more farmers construct raised borders around their orchard to prevent flooding. Fruit burning, a symptom caused by mites, as well as sooty mould *Capnodium citri* Berk. & Desm., a secondary fungal infection accompanying infestations with honeydew-producing Homoptera, were less cited in Dong Thap Province.

Table 2. Percentage of farmers reporting major pests in sweet orange (*C. sinensis*) and Tieu mandarin (*C. reticulata*) with and without abundant *Oecophylla smaragdina* populations in their citrus crop, Mekong Delta, 1998.

Insect species	Local name	Sweet orange		Tieu mandarin	
		ants abundant *n*=42	ants not abundant *n*=12	ants abundant *n*=21	ants not abundant *n*=57
Leafminer	Sau ve bua	85.7	100.0	81.0	94.7
Stinkbug	Bo xit xanh	76.2	83.3	61.9	78.9
Aphids	Ray, ray mem	73.8	100.0[a]	42.9	31.6
Mealybugs	Rep sap	35.7	33.3	38.1	63.2[a]
Scales	Rep dinh	4.8	0.0	9.5	19.3
Citrus red mite	Nhen do	7.1	8.3	47.6	59.6
Fruit piercing moths	Ngai duc trai	31.0	25.0	47.6	43.9
Inflorescence eater	Sau an bong	35.7	50.0	33.3	7.0[b]
Fruit stalk chiseler	Sau duc cuong trai	19.0	16.7	0.0	0.0
Leaf-feeding caterpillar	Sau an la	33.3	75.0[b]	9.5	14.0
Leafroller	Sau cuon la	35.7	25.0	0.0	3.5
Branch borer	Sau duc canh	45.2	41.7	19.0	5.3
Termites and ants	Moi, kien ne	7.1	0.0	28.6	0.0[b]

[1] Multiple answers occurred.
[a,b] Significant differences at the 5% and 1% level, respectively (Pearson χ^2-test).

Use of agrochemicals

A complete list of insecticides used by citrus farmers in the Mekong Delta has been presented in Chapter 4. The majority of the sweet orange farmers sprayed less than four times a year with insecticides. Tieu mandarin farmers practicing weaver ant husbandry sprayed on average seven times a year with insecticides compared to 14 times a year without these ants (Chapter 4).

With abundant *O. smaragdina* in their orchard, significantly fewer sweet orange farmers used the organophosphates monocrotophos (O.R.=0.26, P=0.069) and methamidophos (O.R.=0.10, P=0.023), and significantly fewer Tieu mandarin farmers applied methidathion (O.R.=0.21, P=0.007) and fenobucarb (O.R.=0.15, P=0.084). All these insecticides are classified by the World Health Organization as highly hazardous for humans. Besides, they are extremely harmful to *O. smaragdina* and other beneficial organisms. In preliminary experiments, ants immediately fled to their nest following a spray application with deltamethrin. One day later, many ants were found dead on the ground under the tree. Little by little the ant population increased again, but even after two weeks had not reached its initial number.

The majority of the sweet orange farmers sprayed less than twice a year with fungicides. Tieu mandarin farmers practicing weaver ant husbandry sprayed on average five times a year with fungicides, compared to 10 times without these ants (Chapter 4). Preliminary experiments with propiconazole indicate that sprays did not reduce the number of ants, but significantly decreased the ants' foraging and preying activity for at least two weeks after application. Ants gave the impression of being sick and not hungry.

On average, sweet orange farmers applied about 300 kg of nitrogen, 100 kg of phosphorus and 40 kg of potassium per ha per year and sprayed foliar fertilizers about three times per year, irrespective of *O. smaragdina* (Table 3). Tieu mandarin farmers used more N, P and K (Mann-Whitney U-test, $P<0.01$), and sprayed foliar fertilizers more frequently (Mann-Whitney U-test, $P<0.05$) than sweet orange farmers did. In Tieu mandarin orchards with abundant ants, less N was applied and fewer foliar fertilizers were sprayed than in orchards without *O. smaragdina*. In a preliminary test, a foliar fertilizer application had the same effect on the ants' foraging and preying activity as the fungicide propiconazole.

Pest incidence, severity and yield loss assessment

Tieu mandarin growers assessed insect incidence lower (Kendall's tau-b=-0.08, P=0.079) and yield loss higher (Kendall's tau-b=0.14, P=0.002) than sweet orange farmers did. The number of insecticide sprays targeting a particular insect pest was positively correlated with pest incidence and severity ratings and negatively correlated with ant abundance (Table 4). Insect incidence and severity ratings were correlated in both crops. Sweet orange farmers generally rated insect incidence, severity and yield loss lower when they had *O. smaragdina* in their orchard. This was not the case for Tieu mandarin farmers.

Table 3. Fertilizer use (mean±SE) by farmers cultivating sweet orange (*C. sinensis*) and Tieu mandarin (*C. reticulata*) with and without abundant *Oecophylla smaragdina* populations in their citrus crop, Mekong Delta, Vietnam, 1998.

Fertilizer use	Sweet orange		Tieu mandarin	
	ants abundant *n*=42	ants not abundant *n*=12	ants abundant *n*=21	ants not abundant *n*=57
N (kg/ha)	264.7±28.0^{a}	341.2±87.0^{a}	316.8±39.5^{a}	481.1±41.7^{b}
P (kg/ha)	83.5±10.1^{a}	130.6±32.5^{a}	129.7±17.1^{a}	167.4±16.3^{a}
K (kg/ha)	47.1±9.6^{a}	34.3±9.1^{a}	122.1±23.1^{a}	138.8±18.7^{a}
Foliar fertilizer sprays (no.)[1]	3.2±0.4^{a}	3.1±0.7^{a}	3.4±0.4^{a}	6.7±1.0^{c}
Farmers not using foliar fertilizers (%)	35.7^{a}	25.0^{a}	33.3^{a}	24.6^{a}

[1] Based on those farmers using foliar fertilizers. Data were sqrt (x+0.5) transformed before being tested.
^{a,b,c} Different letters indicate significant differences at the 5% level and 1% level based on Mann-Whitney U-test (kg/ha), Student's t-test (no.) or Pearson χ^2-test (%).

In both crops, aphid infestation was rated lower by farmers with abundant *O. smaragdina* populations (Tables 5 and 6). In sweet orange, citrus leafminer and aphids were rated as the most severe pests. Incidence of leaf-feeding caterpillars was lower with ants. However, reduced yield loss was only recorded for the stinkbug *R. humeralis* and inflorescence eaters. In neither crop, mealybug infestation was rated significantly different when *O. smaragdina* was abundant.

Farmers attributed higher yield losses to diseases than to insects, both in sweet orange (Kendall's tau-b=0.31, $P<0.001$) and Tieu mandarin (Kendall's tau-b=0.23, $P<0.001$). Sweet orange farmers graded the yellow leaf symptom as causing highest yield loss, whereas black spot was most important in Tieu mandarin.

Spray targets

In sweet orange, citrus leafminer and aphids received most of the insecticide target sprays, irrespective of *O. smaragdina* (Table 7). Sweet orange farmers practicing weaver ant husbandry targeted relatively less stinkbug, fruit stalk chiseler and leaf-feeding caterpillars, but more leafrollers. In Tieu mandarin, citrus leafminer and citrus red mite were targeted most. Scales and leaf-feeding caterpillars were relatively less important targets in orchards with *O. smaragdina*. Aphids and inflorescence eaters, on the other hand, were more important targets.

Table 4. Kendall's tau-b correlation coefficients between farmers' perception of insect pests, the number of insect target sprays and abundance of the ant *Oecophylla smaragdina* in different citrus crops, Mekong Delta, Vietnam.

	Pest incidence	Pest severity	Yield loss	No. of target sprays	*O. smaragdina*
Sweet orange					
Pest incidence	1.00				
Pest severity	0.55[b]	1.00			
Yield loss	0.37[b]	0.52[b]	1.00		
No. of target sprays	0.24[b]	0.23[b]	0.19[b]	1.00	
O. smaragdina	-0.16[a]	-0.15[a]	-0.20[b]	-0.27[b]	1.00
Tieu mandarin					
Pest incidence	1.00				
Pest severity	0.34[b]	1.00			
Yield loss	0.30[b]	0.60[b]	1.00		
No. of target sprays	0.21[b]	0.16[a]	-0.03	1.00	
O. smaragdina	-0.02	-0.04	-0.07	-0.28[b]	1.00

[a,b] Significant at P=0.05 and P=0.01 probability levels.

Discussion

Pest perception and use of agrochemicals

Lower ratings of pest infestation could be directly or indirectly attributed to the presence of *O. smaragdina*. A direct positive effect on pest reduction can be claimed to its predatory behaviour. The indirect beneficial effect is that most farmers consciously use less pesticide when *O. smaragdina* is present in their orchard, as such creating a better environment for the survival of other beneficial organisms.

Table 5. Percentage of farmers estimating incidence, severity and yield loss of major sweet orange (*C. sinensis*) pests in relation to abundance of the ant *Oecophylla smaragdina*, Mekong Delta, Vietnam.

Pest	Incidence		tau-b[1]	Severity		tau-b	Yield loss		tau-b
	ants abundant	ants not abundant		ants abundant	ants not abundant		ants abundant	ants not abundant	
Leafminer									
low	14	0		25	9		69	46	
moderate	26	18	-0.21	43	36	-0.22	20	36	-0.19
high	60	82		32	55		11	18	
Stinkbug									
low	34	38		48	50		72	33	
moderate	28	38	0.07	48	25	-0.07	25	33	-0.37[a]
high	38	25		4	25		3	33	
Aphids									
low	28	0		41	9		67	36	
moderate	28	9	-0.40[b]	30	46	-0.25	13	36	-0.22
high	44	91		30	46		20	27	
Mealybugs									
low	33	33		50	67		92	100	
moderate	56	33	0.53	38	33	0.18	0	0	0.11
high	11	33		12	0		8	0	
Inflorescence eater									
low	9	0		44	0		64	20	
moderate	27	25	-0.12	44	75	-0.40	36	60	-0.45[a]
high	64	75		12	25		0	20	
Leaf-feeding caterpillar									
low	15	0		40	43		69	50	
moderate	46	25	-0.37[a]	50	29	-0.08	8	25	-0.14
high	39	75		10	29		23	25	
Leafroller									
low	15	0		20	33		67	33	
moderate	31	33	-0.13	70	33	-0.05	20	33	-0.25
high	54	67		10	33		13	33	

[1] Kendall's tau-b was used to test significance: a,b = significant difference at the 5% and 1% level, respectively. A negative sign before tau-b indicates that estimates were lower when ants were abundant.

Table 6. Percentage of farmers estimating incidence, severity and yield loss of major Tieu mandarin (*C. reticulata*) pests in relation to abundance of the ant *Oecophylla smaragdina*, Mekong Delta, Vietnam.

Pest	Incidence		tau-b[1]	Severity		tau-b	Yield loss		tau-b
	ants abundant	ants not abundant		ants abundant	ants not abundant		ants abundant	ants not abundant	
Leafminer									
low	27	20		17	28		29	28	
moderate	20	26	-0.03	50	45	0.10	64	64	-0.01
high	53	54		33	27		7	8	
Stinkbug									
low	46	38		64	72		55	36	
moderate	36	33	-0.10	36	28	0.09	45	64	-0.19
high	18	29		0	0		0	0	
Aphids									
low	33	0		67	0		100	25	
moderate	50	50	-0.45	33	80	-0.69	0	75	-0.75[b]
high	17	50		0	20		0	0	
Mealybugs									
low	20	32		40	36		25	71	
moderate	60	58	0.13	60	43	-0.14	75	29	0.45
high	20	10		0	21		0	0	
Fruit piercing moths									
low	20	16		50	70		56	44	
moderate	50	42	-0.10	40	30	0.23	44	44	-0.15
high	30	42		10	0		0	11	
Mites									
low	13	22		13	16		0	31	
moderate	50	52	0.13	37	47	0.11	100	61	0.16
high	37	26		50	37		0	8	

[1] Kendall's tau-b was used to test significance: a,b = significant difference at the 5% and 1% level. A negative sign before tau-b indicates that estimates were lower when ants were abundant.

New Tieu mandarin orchards have been established mainly by younger farmers. High pesticide pressure and a less diverse habitat have made conditions for weaver ant husbandry in this crop particularly difficult (Chapter 4). In Tieu mandarin orchards with ants, farmers on average still sprayed insecticides 7 times a year, which could affect *O. smaragdina* predation and the activities of other beneficial organisms. As a consequence, weaver ant abundance had no influence on Tieu mandarin farmers' perception of pests, with the exception of aphids, which were rated lower with ants.

Table 7. Relative importance of citrus insect pests measured as percentage of the total number of target sprays in sweet orange (*C. sinensis*) and Tieu mandarin (*C. reticulata*) in relation to abundance of the ant *Oecophylla smaragdina*, Mekong Delta, 1998.

Insect species	Sweet orange		Tieu mandarin	
	ants abundant *n*=42	ants not abundant *n*=12	ants abundant *n*=21	ants not abundant *n*=57
Leafminer	21.4	18.5	25.7	30.5
Aphids	20.7	26.2	8.8	2.7[b]
Stinkbug	5.5	16.4[b]	8.1	8.1
Mites	1.1	0.0	37.2	29.8
Mealybugs	7.0	6.2	6.1	11.1
Scales	3.0	0.0	0.7	7.8[b]
Fruit piercing moths	2.6	2.1	3.4	2.7
Inflorescence eater	6.6	11.3	8.1	0.3[b]
Fruit stalk chiseler	2.6	8.2[b]	0.0	0.0
Leaf-feeding caterpillar	3.7	9.2[a]	0.0	7.0[b]
Leafroller	14.8	2.1[b]	0.0	0.0
Termites and ants	3.0	0.0	2.0	0.0
Psyllids	5.2	0.0	0.0	0.0
Branch borer	3.0	0.0	0.0	0.0

[a,b] Significant differences at P=0.05 and P=0.01 probability levels, respectively (Pearson χ^2-test); no letters indicate no significant difference.

In Tieu mandarin, less nitrogen and fewer foliar fertilizers were applied when ants were abundant. Despite a reduced input of fertilizers and pesticides, yields were not affected (Chapter 4). Barzman *et al.* (1996) showed that ants played an important role in improving the external shine and fruit juiciness, an effect which, according to the citrus farmers, could be partially replaced by fertilizers.

Citrus leafminer and stinkbug

Nearly all farmers mentioned citrus leafminer and citrus stinkbug as important citrus pests. Stinkbugs were a less important spray target in sweet orange when ants were abundant. The importance of predation of ants on stinkbug has been previously reported in China (Huang and Yang, 1987). *Oecophylla* might also reduce leafminer populations (Barzman, Mills and Cuc, unpublished). However, in both cropping systems, citrus leafminer was a major spray target, irrespective of the presence of *O. smaragdina*. The high visibility of the symptoms makes this pest an important target for farmers.

Chemical control has been described as not viable because of the cost of multiple applications, the inaccessibility of larvae within the mine and the likely development of resistance (Waage, 1989). In China, resistance against pyrethroids has been illustrated since the 1980s (CABI, 1998). Enhancing natural enemies of citrus leafminer and stimulating synchronous flushing can be integrated with the use of petroleum spray oils (PSO) (Smith *et al.*, 1997; Huang and Tan, 1998). Researchers and staff from the Plant Protection Department (PPD) and Extension Service in Vietnam should try to focus on conservation or augmentation of natural enemies rather than recommending chemical control.

Mealybugs and scales

Increased problems with scales, mealybugs, mites and thrips are typical for situations where the natural enemies have been killed due to excessive use of broad-spectrum insecticides and where pests have developed resistance (Hill and Waller, 1988, Waite, 1998). Tieu mandarin farmers indeed use high chemical inputs. They are highly flexible to changes in the pesticide market, being eager to try out new products, irrespective of the higher price (Chapter 4). The number of insecticide products used in fruit production doubled from 1994 to 1998, nearly all had broad-spectrum activity (Van Mele and Hai, 1999). PSO have been registered in Vietnam only since 1999. When promoting their use in citrus, care will have to be taken to avoid phytotoxicity as Tieu mandarin farmers are used to spraying very frequently. Fruit farmers in Vietnam are not familiar yet with monitoring and proper timing of application.

It has been reported that *Oecophylla* does not attack parasitoids and predators of mealybugs and scales (Huang and Yang, 1987; Olkowski and Zhang, 1998). Citrus farmers in China did not perceive damage caused by mealybugs as significant when weaver ants were present. Similarly, in neither sweet orange nor Tieu mandarin orchards in the Mekong Delta, Vietnam, was mealybug infestation correlated with ant abundance.

Mites

As Tieu mandarin is an economically more profitable crop than sweet orange, the cosmetic appearance is very important (Chapter 4). Hence, mites were one of the most important spray targets. Up to now, many citrus farmers in the Mekong Delta still apply a lot of organophosphates (OPs) which are detrimental for all kinds of natural enemies, pollinators, fish and human beings (Chapter 4). Mites are mostly targeted with methidathion, fenpropathrin and several selective acaricides at regular intervals during the rainy season (Chapter 7). Worldwide, resistance of spider mites against OPs has been reported since the 1950s and later on also against carbamates, pyrethroids and selective acaricides (Helle and van de Vrie, 1974; Ho, 1984; Reissig and Hull, 1991; Goodwin *et al.*, 1995; Smith *et al.*, 1997). Besides, several fungicides such as benomyl and mancozeb reduced populations of the predatory mite *Amblyseius victoriensis* (Acarina: Phytoseiidae) by 100% (Smith and Papacek, 1991). Copper oxychloride, which fulfils the same disease-control function, was non-toxic to *A. victoriensis*.

Promoting weaver ant husbandry and reduction of pesticide use in Tieu mandarin will only be successful when mites can be controlled simultaneously without excessive chemical treatments. In Vietnam, no research has been done to evaluate the diversity and importance of predatory mites. So far, only about four different species of the small, black predatory ladybeetle *Stethorus* spp. (Coleoptera: Coccinellidae) have been identified as natural enemies of mite pests (P.V. Lam, pers. comm., 2000). After making an inventory of all beneficials, interactions of these natural enemies with O. *smaragdina* will have to be evaluated as well as the impact of different pesticides on these organisms.

Extension

So far, weaver ant husbandry has been neglected in most extension activities. Training of young farmers, plant protection and extension staff by both scientists and more experienced, older farmers who practice weaver ant husbandry, could offer good possibilities in a society where Confucianism is part of daily life. In Confucianism, both teachers and elders are highly respected. Farmers relying on extension for pesticide advice sprayed fungicides more frequently, and those relying on extension and media applied more insecticide sprays (Chapter 6).

The challenge is to devise ways to interest staff from the PPD and Extension Service in promoting the use of O. *smaragdina* and in reducing pesticide applications. So far, no scientific information exists on predatory mites in Vietnam. In the future, rearing facilities could be developed to commercialize natural enemies such as phytoseiid mites like

Amblyseius spp. Involvement of PPD and extension officers in production, promotion and distribution of natural enemies might offer good opportunities.

References

Barzman, M. S., Mills, N. J. and Cuc, N. T. T. 1996. Traditional knowledge and rationale for weaver ant husbandry in the Mekong Delta of Vietnam. Agriculture and Human Values, 13(4), 2-9.

CABI 1998. Crop Protection Compendium – CDRom Module 1. CAB International, Wallingford, U.K.

Farrington, J. 1988. The role of indigenous technical knowledge. In: J. Farrington and A. Martin (eds) Farmer Participation in Agricultural Research. Overseas Development Insitute, pp. 23-29.

Fujisaka, S. 1990. Rainfed lowland rice: building research on farmer practice and technological knowledge. Agriculture, Ecosystems & Environment, 33, 57-74.

Goodwin, S., Herron, G., Gough, N., Wellham, T., Rophail, J. and Parker, R. 1995. Relationship between insecticide-acaricide resistance and field control in *Tetranychus urticae* (Acari: Tetranychidae) infesting roses. Journal of Economic Entomology, 88, 1106-1112.

Gurr, G. M., van Emden, H. F. and Wratten, S. D. 1998. Habitat manipulation and natural enemy efficiency: implications for the control of pests. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 155-183.

Helle, W. and van de Vrie, M. 1974. Problems with spider mites. Outlook on Agriculture, 8, 119-125.

Hill, D. S. and Waller, J. M. 1988. Pests and Diseases in Tropical Crops, Volume 2. Longman Scientific and Technical, New York, pp. 432.

Ho, K. Y. 1984. Observation on resurgence of citrus red mite, *Panonychus citri* (Mc Gregor) following pesticide applications. Plant Protection Bulletin Taiwan, 26, 99-108.

Huang, H. T. and Yang, P. 1987. The ancient cultured citrus ant. Bioscience, 37, 665-671.

Huang, M. and Tan, B. 1998. Ecology and management of citrus leafminer in China: a review. In: Proceedings of the International Conference of IPM. Guangzhou, China, p. 134.

Liang, W. G. and Huang, M. D. 1994. Influence of citrus orchard ground cover plants on arthropod communities in China: a review. Agriculture, Ecosystems & Environment, 50, 29-37.

Löhr, B. 1992. The pugnacious ant, *Anoplolepis custodiens* (Hymenoptera: Formicidae) and its beneficial effect on coconut production in Tanzania. Bulletin of Entomological Research, 82, 213-218.

Matteson, P. C., Altieri, M. A. and Gagné, W. C. 1984. Modification of small farmer practices for better pest management. Annual Review of Entomology, 29, 383-402.

Morse, S. and Buhler, W. 1997. Integrated pest management: Ideals and Realities in Developing Countries. Lynne Riener Publishers, London, 171 pp.

Olkowski, W. and Zhang, A. 1998. Habitat management for biological control, examples from China. In: C. H. Pickett and R. L. Bugg (eds) Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, California, pp. 255-270.

Peng, R. K., Christian, K. and Gibb, K. 1995. The effect of the green ant *Oecophylla smaragdina* (Hymenoptera: Formicidae), on insect pests of cashew trees in Australia. Bulletin of Entomological Research, 85, 279-284.

Peng, R. K., Christian, K. and Gibb, K. 1999. The effect of colony isolation of the predacious ant, *Oecophylla smaragdina* (F.) (Hymenoptera: Formicidae), on protection of cashew plantations from insect pests. International Journal of Pest Management, 45, 189-194.

Pickett, C. H. and Bugg, R. L. 1998. Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, California, 433 pp.

Reissig, W. H. and Hull, L. A. 1991. Hexythiazox resistance in a field population of European red mite (Acari: Tetranychidae) on apples. Journal of Economic Entomology, 84, 727-735.

Smith, D. and Papacek, D. 1991. Studies of the predatory mite *Amblyseius victoriensis* (Acarina: Phytoseiidae) in citrus orchards in south-east Queensland: control of *Tegolophus australis* and *Phyllocoptruta oleivora* (Acarina: Eriophyidae), effect of pesticides, alternative host plants and augmentative release. Experimental and Applied Acarology, 12, 195-217.

Smith, D., Beattie, G. A. C. and Broadly, R. 1997. Citrus Pests and Their Natural Enemies. Integrated Pest Management in Australia. Queensland Department of Primary Industries, Brisbane, 272 pp.

Thrupp, L. A. 1989. Legitimizing local knowledge: from displacement to empowerment for third world people. Agriculture and Human Values, 6(3), 13-24.

Van Mele, P. and Hai, T. V. 1999. Pesticide Use in Orchards in the Mekong Delta of Vietnam. In: Proceedings of the 5th International Conference on Plant Protection in the Tropics, Kuala Lumpur, March 15-18th, 1999, pp. 529-533.

Waage, J. K. 1989. The population ecology of pest - pesticide - natural enemy interactions. In: Jepson, P. C. (ed) Pesticides and Non-target Invertebrates. Intercept, Wimborne, U.K., pp. 81-93.

Waite, G. K. 1998. Integrated pest management in tropical and subtropical fruits in Queensland. In: Proceedings of the International Conference of IPM. Guangzhou, China, p. 135.

Way, M. J. 1963. Mutualism between ants and honeydew producing Homoptera. Annual Review of Entomology, 8, 307-344.

Zadoks, J. C. 1993. Crop protection: why and how. In: Chadwick, D. J. and Marsh, J. (eds) Crop Protection and Sustainable Agriculture. John Wiley and Sons, New York, pp. 48-55.

6. Influence of pesticide information sources on citrus farmers' knowledge, perception and practices in pest management

Abstract

In 1998-1999, about 150 citrus farmers and 120 pesticide sellers were interviewed in Can Tho and Dong Thap Province, Mekong Delta, Vietnam. Media, pesticide sellers and extension staff had different types of influence on farmers' pest perception and management practices depending on the region and intensity of the cropping system. Pesticide sellers were notified by about 95% of the farmers about their major pest problems, and the type of pesticides sold in their shop was primarily based on farmers' demand (87%) and secondly on company promotion (56%). In the intensive Tieu mandarin cropping system, media and extension activities increased farmers' knowledge of difficult-to-observe pests such as the citrus red mite *Panonychus citri* and thrips, *Thrips* sp. and *Scirtothrips* sp. Since extension was weak in sweet orange, those farmers exposed to media only reported the damage symptom of mites, not knowing the causal agent. Media alone seemingly did not suffice to acquaint farmers with these small organisms. Farmers getting advice from the media advertisements applied more different pesticide products, and sprayed insecticides more frequently, whereas the extension has stimulated the use of acaricides and increased the number of both insecticide and fungicide sprays. The traditional practice of biological control with the ant *Oecophylla smaragdina* might be endangered with growing media influence and when extension activities remain confined to chemical pest control. Constraints and potentials of different information sources are discussed in relation to developing IPM programmes for citrus.

Introduction

One of the major constraints in establishing an IPM programme is the lack of adequate information about farmers' knowledge, perceptions and practices (KPP) in pest management (Norton and Mumford, 1982; Kenmore, 1991; Morse and Buhler, 1997). Knowledge of pests not only vary between farmers working in different agro-ecosystems, but also between those working in similar ones (Altieri, 1993; van Huis and Meerman, 1997; Debrah *et al.*, 1998). Evaluating farmers' KPP is especially useful to determine information gaps, to set research agendas, to assess the impact of different information sources, to plan campaign strategies and to develop messages for communication (Kenmore *et al.*, 1987; Fujisaka, 1992; Escalada and Heong, 1993; Mumford and Norton, 1993; Heong *et al.*, 1998). Farmers' KPP in controlling pests have been well-documented for rice (Adesina *et al.*, 1994; Heong and Escalada, 1997) among other crops, but it is non-existent for tropical fruit crops. Besides, relatively few scientific papers address farmers' pesticide use patterns, which in many cases in developing countries is a major component of pest management (Heong and Escalada, 1997; Burleigh *et al.*, 1998).

Our survey focused on citrus farmers' KPP in pest management and how this was influenced by different sources of pesticide information. Of particular interest were (i) the kind of pests that farmers perceived as problematic; (ii) farmers' use of agrochemicals and their spray patterns; and (iii) the traditional use of the weaver ant *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae) as a biological control agent.

Materials and methods

From January to April 1998, 150 citrus farmers, cultivating mainly sweet orange (*Citrus sinensis* (L.) Osbeck) and Tieu mandarin Blanco), and to a lesser extent sweet mandarin (*C. reticulata*) and king orange (*C. nobilis* Lour.), were interviewed in Can Tho and Dong Thap Province, Mekong Delta, Vietnam. Sampling was stratified according to the production area of each citrus species. Within each stratum, farmers were randomly selected based on a list held by the Service of Agriculture and Rural Development. One criterion was that orchards had to be at least four years old. Sweet orange, sweet mandarin and king orange cultivation was mainly restricted to Can Tho Province and farmers were interviewed in Can Tho City, Chau Thanh and Omon District (n=72). Tieu mandarin is very susceptible to flooding and therefore is mainly grown in those areas with a slightly higher elevation and on soils that allow better drainage. Sampling for Tieu mandarin was consequently carried out in Omon District of Can Tho Province and in Lai Vung District, Dong Thap Province (n=78).

The content of the questionnaire and type of questions asked was agreed upon after key informant interviews and was modified after being pretested on a small group of farmers in both Provinces. On average, each questionnaire took 2-3 hours of interview with each farmer. People involved in the survey were members of the Plant Protection Department, Cantho University. The questionnaire was aimed at getting a clear picture of the farming system in general, and about the farmers' knowledge, their perceptions and the pest management they carried out. Both structured and semi-structured open questions were used as described by Mumford and Norton (1993). Farmers were asked to record their most important pest problems and to indicate where they got information about pesticide use. They could choose one or more out of the following list: own experience, media, pesticide sellers, neighbours, extension staff, university staff, staff from research institute or other. Although no explicit distinction was made for media, previous studies in the Mekong Delta have indicated that TV was much more important than radio for both fruit farmers (Dang, 1997) and rice farmers (Chung and Dung, 1996). In cases where pesticides were used, farmers were asked to specify which products they used and how many times, when they sprayed, and which pests were targeted.

Expert surveys assessed the content and importance of different information flows towards farmers. Information about extension activities was obtained through interviews with key persons from the Extension Service in the different districts. Staff from the Plant Protection Service and Cantho University were also interviewed. In general, the Plant Protection Service was not very familiar with pest management in fruit crops, but had an indirect impact on fruit farmers by giving training courses to pesticide sellers. Media activities were recorded and analysed at regular times throughout the study period. Specific information about the pesticide seller's knowledge of pests and pesticides, and their interaction with the farmers were obtained from a separate survey conducted at the end of 1998, beginning of 1999. In those districts where the farmer survey had been conducted, about 120 pesticide shop owners were randomly selected and interviewed using a questionnaire. Fifty two of them reported to sell pesticides to citrus farmers on a regular basis. The pesticide sellers were also asked to list the, according to them, four most important pests and diseases. They were finally presented with a list of the 10 most important citrus pests and diseases and asked for each of these to record up to three different products which they would recommend.

Survey data were encoded using spreadsheet software programmes and statistical analysis were accomplished using SPSS statistical software. Chi-squared and Cramer's V were calculated to indicate correlations between dichotomous variables. Logistic regressions were conducted for dichotomous variables such as information source and use of agrochemicals. Except for these dichotomous variables, other variables included in the analyses were: production regions (four districts entered as dummy variables), farmers' age and education (years), the size (ha) of the orchard and age (years) of the trees, the type of major fruit species (Tieu mandarin, sweet orange and others entered as dummy variables), mixed or monoculture (dichotomous), the plant density (trees/ha), and high weaver ant populations or not (dichotomous). Detailed information about these variables have been given in Chapters 4 and 5. Calculations were routinely done including all independent variables. At each step the variable with the highest P value was omitted until only significant ($P<0.05$) variables remained in the model (Backward Model Selection). To enable comparisons of types of pesticides used and types of pests reported between the different information sources, one general model was build including all the variables that were significant in at least one of the individual models of each information source (Agresti, 1990). Odds ratio's (OR) are given for each independent variable. An OR smaller than one indicates that the probability that the dependent variable occurs is smaller than the probability in the reference class of the independent factor (the reference class is always indicating the absence or the negation of the independent variable), and vice versa when the OR is higher than one. Degrees of freedom are one, unless stated otherwise.

GLM general factorial analysis allowing for two-way interactions were conducted to find out which production characteristics and pesticide information sources discriminated for differences in the number of pests reported, the number of pesticide products applied and the number of sprays. The regression coefficients B and their respective probability values P are given for all significant variables and interactions.

Results and discussion

Who gets pesticide advice where and from who?

About 60% of the farmers relied on their own experience for pesticide advice, 40% on media advertisements, and 20% on pesticide sellers, followed by extension officers (17%), neighbours (7%) and university staff (5%) (Figure 1). Analyzing the within-district correlation of different information sources, own experience was strongly correlated with advice from the media in Can Tho City (Cramer's V=0.919, P<0.001), and with advice from the pesticide sellers in Chau Thanh District (Cramer's V=0.407, P=0.023).

Table 1. Odds ratio's (P-value) of production characteristics for different sources of pesticide advice, Mekong Delta, 1998 (*n*=150). Bold figures indicate discriminating variables at P≤0.05 for individual models of information source.

	Own experience	Media	Pesticide seller	Extension officer	Neighbour
Omon District	**5.57** (0.00)	1.72 (0.35)	0.39 (0.16)	0.36 (0.41)	-[1]
Can Tho City	2.57 (0.06)	**3.73** (0.02)	0.24 (0.04)	1.41 (0.69)	-
Lai Vung District	1.91 (0.36)	1.84 (0.37)	0.67 (0.63)	**10.68** (0.03)	-
Tieu mandarin	0.77 (0.64)	0.91 (0.85)	0.51 (0.34)	0.41 (0.35)	**3.00** (0.34)

[1] Odds ratio's could not be calculated because of insufficient data.

Logistic regression analysis revealed that the production area and type of citrus species cultivated had the most discriminating power. The significant variables were grouped in one model to make comparisons between the different information sources possible (Table 1). Chau Thanh District was omitted from the model to avoid colinearity.

The media were the most important source of pesticide information for farmers in Can Tho City, which hosts the biggest TV station in the Mekong Delta, and the pesticide sellers had most influence in Chau Thanh District (OR=3.32, P=0.007). Extension was most significant in Lai Vung District, Dong Thap (Table 1). The Extension Service of this province has a strong programme supporting fruit production, whereas in Can Tho Province extension mainly focuses on rice and vegetable production. Neighbours were only important for information exchange in Tieu mandarin, irrespective of the Province.

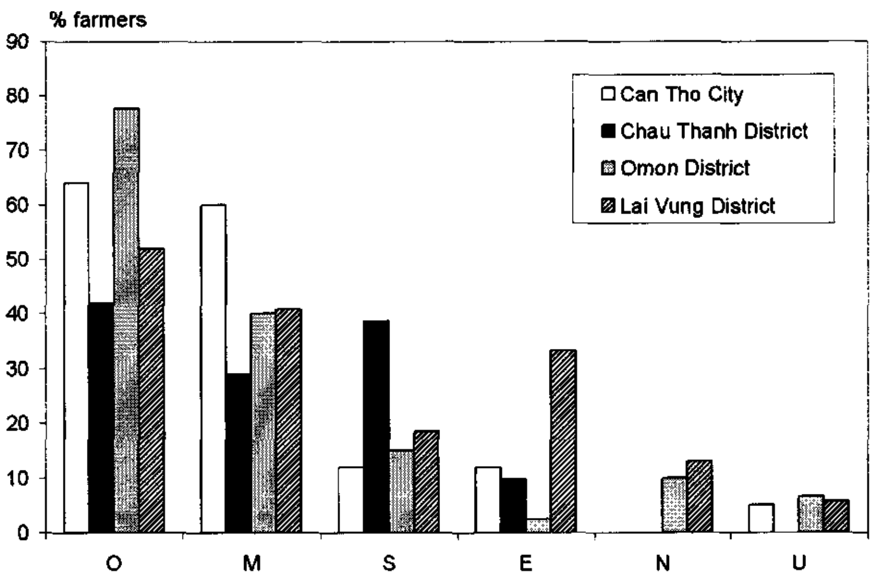

Figure 1. Sources of information influencing farmers' decision-making related to pesticide use in different citrus production regions. O=own experience, M=media, S= pesticide seller, E=extension officer, N=neighbour.

Most of the pesticide sellers had a high education level, on average 9.8 (SE=0.4) years of school, and they have been in the business for about 7.0 (SE=0.7) years. Some of them have learned about pests by self-study in books or by observing pests in their own orchard (Table 2). They were mainly informed by the farmers about the current pest problems and about the performance of pesticides. Information about pesticides was also obtained from activities organized by the chemical companies and from media advertisements. The Plant Protection and Extension Service hardly seemed to contribute to the pesticide seller's knowledge about pests.

Table 2. Percentage of pesticide sellers reporting their information sources for learning about pests and pesticides[1], Mekong Delta, 1998-1999 (n=52).

	Where did pesticide seller learn about		
	pests	current pest problems	products
Farmer	9.6	69.2	84.6
Company	0.0	13.5	69.2
Media	0.0	9.6	59.6
Leaflets	0.0	0.0	38.5
Plant Protection Service	7.7	9.6	32.7
Extension Service	0.0	0.0	28.8
Cantho University	0.0	0.0	25.0
Books	26.9	0.0	0.0
Own experience	15.4	0.0	7.7
Nowhere	0.0	3.8	0.0

[1] Multiple answers occurred.

Pest problems

The number of insect pests reported by farmers depended mainly on the pesticide information source, of which media was most significant (Table 3). A list of major insect pests and diseases in citrus in the Mekong Delta has been presented in Chapter 5.

The citrus leafminer *Phyllocnistis citrella* (Lepidoptera: Gracillariidae) was the most frequently mentioned insect pest by farmers irrespective the crop, production region or information source. Pesticide sellers (85%) also reported this as the most important pest in citrus. The citrus stinkbug *Rhynchocoris humeralis* (Heteroptera: Pentatomidae) and mealybugs *Planococcus citri* (Risso) (Homoptera: Pseudococcidae) were mainly mentioned by farmers who relied on their own experience for purchasing pesticides (Table 4). The pesticide sellers were notified by more than 90% of the farmers about their major pest problems. The stinkbug and mealybugs were mentioned by about 25% and 50% of the pesticide sellers as major citrus pests. Despite the fact that citrus greening has been the major topic for fruit extension activities in Can Tho Province since 1994, it is surprising that only six farmers and one pesticide seller reported its vector, the psyllid *Diaphorina citri* (Kuwayama) (Homoptera: Psyllidae), as a pest problem.

Some pests are never dealt with in the media or extension activities. Pesticide advice to control some easily observable pests such as leafrollers (unidentified; Lepidoptera: Tortricidae) and stem borers (Coleoptera: Cerambycidae) was only asked to the pesticide seller.

Table 3. General linear model parameter estimates for the number of insect pests and diseases reported by citrus farmers (*n*=150), Mekong Delta, 1998.

	No. of insect pests		No. of diseases	
	B[1]	P	B	P
Own experience	0.72	0.028	0.79	0.006
Media	1.33	<0.001	1.64	<0.001
Extension	-	-	1.05	0.006
Omon District	-	-	1.74	<0.001
Intercept	3.72	<0.001	2.59	<0.001

[1] B=regression coefficient, P=probability.

The source of pesticide advice may affect farmers' knowledge of pests, and especially of those that are difficult to observe. Thrips, *Thrips* sp. and *Scirtothrips* sp. (Thysanoptera), were only reported by farmers who relied on the extension staff and/or media for their pesticide advice (Table 4). The citrus red mite *Panonychus citri* (Mc Gregor) (Acarina: Tetranychidae) was mainly mentioned as a pest problem when the neighbour or the extension staff was an important pesticide information source. The symptoms caused by the citrus red mite and the citrus rust mite *Phylocoptruta oleivora* Ashmead (Acarina: Eriophyiidae), on the other hand, were reported as diseases mainly by farmers depending on the media for advice. One extension video dealing with mites has been made by staff from the Cantho University in collaboration with the Extension Service. This is broadcasted at regular intervals at the beginning of each fruiting season. Although pictures of mites are displayed, this seemingly does not contribute to the farmers' knowledge of the organism. With pictures, pests are magnified so much that they no longer reflect the real situation. Some extension activities with field visits and the provision of hand lenses were conducted to assist farmers in recognizing mites. However, during our survey only some farmers were observed having hand lenses. Considering the fact that mites are very small, highly mobile creatures, and therefore difficult to observe under field conditions, it is surprising that 75% of the Tieu mandarin farmers in Dong Thap mentioned mites in their orchard (Chapter 5). Most farmers have probably never observed mites, and just sprayed their orchard prophylacticly based on extension and media advice. Tieu mandarin farmers indeed calendar sprayed their orchard against mites from flowering until harvest (Chapter 7). Farmer training through extension seminars or mass media, out of the context of their own field, indeed has often led to such situations where farmers were told which pests they had and how to chemically control them (Escalada and Heong, 1993; van de Fliert, 1993). In such cases, it is not the farmer but the extension staff, scientist or media who is the decision-maker. Tieu mandarin farmers are seemingly highly receptive to provided information and whether they actually know mites should be further investigated by confronting them with life samples.

Table 4. Odds ratio's (P-value) of major pests reported by farmers relying on different sources of pesticide advice, Mekong Delta, 1998 (n=150). Bold figures indicate discriminating variables at P≤0.05 for individual models of information source.

	Own experience	Media	Pesticide seller	Extension officer	Neighbour
Pests					
Stinkbug	**2.60** (0.03)	0.83 (0.68)	1.07 (0.89)	0.57 (0.32)	0.43 (0.29)
Mealybugs	**3.95** (0.00)	1.31 (0.57)	0.70 (0.49)	0.64 (0.44)	0.48 (0.43)
Leaf-feeding caterpillar	2.78 (0.05)	**4.40** (0.00)	1.26 (0.67)	0.98 (0.97)	-[1]
Leafroller	0.77 (0.63)	1.63 (0.40)	**2.76** (0.07)	0.28 (0.27)	-
Stem borer	0.43 (0.45)	0.19 (0.00)	**27.20** (0.02)	1.45 (0.79)	-
Thrips	1.72 (0.55)	**8.79** (0.02)	1.10 (0.94)	**12.95** (0.00)	0.73 (0.83)
Mites	0.59 (0.26)	1.52 (0.39)	0.87 (0.80)	**2.44** (0.11)	**8.24** (0.01)
Diseases					
Red mite symptom	**3.60** (0.06)	**4.04** (0.02)	1.86 (0.32)	1.24 (0.77)	-
Rust mite symptom	1.37 (0.65)	**4.66** (0.03)	0.41 (0.28)	2.36 (0.24)	7.65 (0.14)
Sooty mould	2.00 (0.18)	**2.65** (0.05)	0.76 (0.63)	0.49 (0.29)	1.83 (0.56)
Black spot	0.86 (0.73)	0.89 (0.79)	0.77 (0.59)	**2.47** (0.11)	**0.17** (0.05)

[1] Odds ratio's could not be calculated because of insufficient data.

Use of agrochemicals

Insecticide use was correlated with fungicide use (Cramer's V=0.439, P<0.001) and foliar fertilizer use (Cramer's V=0.206, P=0.012). Whether farmers used insecticides or not depended mainly on the presence of the ant *O. smaragdina* (Table 5). Sweet orange farmers in Can Tho Province often resume from spraying insecticides to conserve *O. smaragdina* as a biological control agent in their orchard (Chapter 4).

Table 5. Odds ratio's (P-value) from logistic regression models for use of agrochemicals based on production characteristics, pesticide information sources and pests mentioned by farmers, Mekong Delta, 1998 (*n*=150).

	Insecticide use	Fungicide use	Herbicide use	Foliar fertilizer use
Can Tho City	-[1]	-	4.39 (0.006)	-
Omon District	4.39 (0.020)	-	-	-
Lai Vung District	10.74 (0.035)	-	-	-
Tieu mandarin	-	14.99 (0.00)	-	-
Size orchard	-	-	1.16 (0.013)	-
Mixed orchard	4.97 (0.020)	-	-	-
O. smaragdina	0.08 (0.018)	-	-	-
Age farmer	-	-	0.96 (0.033)	-
Media	-	3.28 (0.014)	-	2.15 (0.065)
Own experience	-	2.99 (0.020)	2.65 (0.035)	-
Neighbour	-	-	7.74 (0.007)	-
Thrips	-	-	8.46 (0.016)	-
Aphids	-	-	-	2.01 (0.074)
Mealybugs	-	-	-	3.50 (0.004)
Scab	-	2.61 (0.041)	-	-

[1] Non-significant variables were omitted from the model.

Fungicide use was best discrimated by Tieu mandarin and whether farmers relied on media for pesticide advice. Most farmers reporting scab, *Elsinoë fawcettii* Bitanc. et Jenkins, applied fungicides. Daily, agricultural programmes are broadcasted by Cantho TV in all the provinces of the Mekong Delta. The majority of these programmes are developed by agrochemical companies promoting products for pest and disease control in rice, vegetables and fruit. Also the extension video's made by the staff from the Cantho University recommend the prophylactic use of acaricides, insecticides and fungicides.

The majority of farmers applied hand weeding and only about 30% used herbicides (Van Mele and Phen, 1999). Herbicide use was best predicted by farmers reporting thrips as a pest problem and by those reporting the neighbour as a pesticide information source. Herbicides were also more frequently used in larger orchards.

Foliar fertilizers were mostly applied by farmers reporting mealybugs and aphids *Toxoptera aurantii* and *T. citricidus* (Homoptera: Aphididae) to be a problem, and by those reporting media as a pesticide information source. Seemingly the promotion of foliar fertilizers goes hand in hand with the promotion of pesticides and occurrence of certain pests.

Pesticide choice

The number of pesticide products applied was significantly higher in Tieu mandarin, and when farmers got advice from the media or staff from the university (Table 6). Farmers keeping weaver ants in their orchard used less different products.

Table 6. General linear model parameter estimates for the number of pesticide products purchased by citrus farmers (*n*=150), Mekong Delta, 1998.

	No. of pesticides	
	B[1]	P
Media	1.92	<0.001
University	2.58	0.023
O. smaragdina	-1.78	0.001
Tieu mandarin	2.29	0.001
Mixed orchard	1.45	0.024
Lai Vung District	2.21	<0.001
Intercept	2.29	<0.001

[1] B=regression coefficient, P=probability.

Pesticides are mostly promoted by involving famous singers of the traditional opera *Cai luong*, national athletes, handsome ladies or farmers. The message is that when using pesticides economic benefits are always guaranteed. The major insecticides used in Can Tho were methyl parathion (Methylparathion), monocrotophos (Azodrin), alpha-cypermethrin (Cyper-Alpha and Fastac) and methamidophos (Monitor) (Chapter 4). Nearly all of the major pesticide products used in Can Tho Province are distributed by Cantho Pesticides Company. Alpha-cypermethrin, promoted by pesticide sellers and by the media (Table 7), was mainly applied against the citrus leafminer.

Table 7. Odds ratio's (P-value) of major pesticides used by citrus farmers who rely on different sources of pesticide advice, Mekong Delta, 1998 (*n*=150). Bold figures indicate discriminating variables at P≤0.05 for individual models of information source.

	Own experience	Media	Pesticide seller	Extension officer	Neighbour
Insecticides/acaricides					
Alpha-cypermethrin	**2.68** (0.07)	**3.22** (0.01)	**2.75** (0.06)	0.77 (0.75)	0.85 (0.88)
Methyl parathion	2.13 (0.20)	1.37 (0.55)	**3.12** (0.07)	-[1]	0.54 (0.65)
Carbofuran	0.96 (0.95)	0.86 (0.82)	1.54 (0.57)	0.04 (0.35)	-
Propargite	1.55 (0.64)	0.84 (0.84)	8.82 (0.08)	0.36 (0.37)	**33.89** (0.02)
Fenpropathrin	2.89 (0.23)	0.38 (0.29)	0.12 (0.14)	**11.83** (0.01)	13.16 (0.07)
Sulphur	**0.18** (0.06)	2.34 (0.34)	0.06 (0.06)	**22.45** (0.01)	21.28 (0.09)
Hexythiazox	0.65 (0.67)	0.55 (0.57)	1.70 (0.75)	**0.04** (0.02)	0.06 (0.22)
Fenpyroximate	1.14 (0.89)	**8.98** (0.04)	1.44 (0.83)	0.29 (0.31)	-
Fungicides					
Zineb + Bordeaux	**5.28** (0.03)	0.86 (0.80)	-	5.31 (0.05)	0.27 (0.39)
Zineb	0.53 (0.38)	1.55 (0.50)	**0.11** (0.11)	0.44 (0.51)	**26.82** (0.00)
Carbendazim	0.76 (0.61)	**2.02** (0.18)	0.41 (0.29)	1.09 (0.91)	2.43 (0.43)
Kasugamycin + Copper oxychloride	0.42 (0.18)	1.74 (0.37)	1.48 (0.64)	**3.38** (0.10)	0.14 (0.18)
Fosetyl aluminium	1.72 (0.40)	1.36 (0.63)	3.30 (0.21)	1.04 (0.97)	0.23 (0.27)

[1] Odds ratio's could not be calculated because of insufficient data.

Implementation of pesticide regulations is still weak and should be enforced. Farmers relying on the pesticide seller applied more of the banned product methyl parathion (Table 7), mainly against aphids and mealybugs. Although the type of pesticides sold in shops was primarily based on farmers' demand (87%) and secondly on company promotion (56%) (Table 8), surprisingly, none of the sellers mentioned that farmers still asked for these products. Despite this, in the beginning of 1998 still about 15% of the citrus farmers reported applying this product (Chapter 4). Similarly, in 1998 several vegetable farmers in Can Tho Province reported applying methyl parathion and carbofuran (Hai *et al.*, 2000). One possibility is that farmers have bought large stocks of these products before these were banned, or that these products are still sold under the counter.

Tieu mandarin farmers in Dong Thap most frequently applied methidathion (Supracide), fenpropathrin (Danitol), imidacloprid (Admire and Confidor) and sulphur (Microthiol and Kumulus) (Chapter 4). Except for imidacloprid, these products were mainly used against mites. Because most farmers in Dong Thap applied methidathion and imidacloprid for targeting the citrus leafminer (Chapter 7), no statistical differences between sources of information could be observed. The frequent use of the above mentioned pesticides most likely has a disastrous effect on weaver ants and other beneficial organisms, creating new pest problems.

Table 8. Criteria on which pesticide sellers select the products they sell in their shop, Mekong Delta, 1998-1999.

	Rank of importance[1]			
	1	2	3	4
Farmers ask specific product	86.5	3.8	1.9	0.0
Company promotes product	9.6	55.8	9.6	0.0
TV advertisement	0.0	11.5	42.3	0.0
Radio advertisement	0.0	0.0	7.7	17.3

[1] 1 = most important, 2 = second most important,...

The media actively promoted the acaricide fenpyroximate (Ortus) (Table 7). Pesticide sellers promoted the acaricide propargite (Comite), which gained further popularity by farmer-to-farmer propaganda. Fenpropathrin against mites and thrips, and sulphur (Microthiol) against mites were strongly advertised by the extension service. These were the cheapest products to control mites (Table 9). Only propargite has been reported to have low toxicity for most natural enemies (Flint, 1991), but it is more expensive than the other acaricides available on the market. Microthiol was produced by Cantho University in 1996-1997 and strongly promoted against mites by the extension staff and farmer-to-farmer propaganda. It was sold at one-third of the market price of another commercial sulphur formulation, namely Kumulus. By now, Microthiol is also produced by a commercial company and sold equally expensive.

About 45% of all Tieu mandarin farmers used kasugamycin + copper oxychloride (Kasuran). This product was mainly promoted by the extension and media against citrus canker, *Xanthomonas campestris* pv. *citri* (Hasse) Dye. The fungicide Zineb + Bordeaux (Copper Zinc) is produced by the Cantho University and is strongly promoted by the Extension Service. About 10% of the farmers used it, some of them applying it against the citrus greening disease that is sometimes confused with Zn-deficiency. Zineb (Zineb), sprayed by about 10% of the Tieu mandarin farmers, and mainly for controlling sooty mould, was purchased by those farmers who got to know about the efficiency of this product from their neighbours. Fosetyl aluminium (Aliette), applied by about 40% of the Tieu mandarin farmers, was the main product promoted by the pesticide sellers for controlling citrus canker (42%) and root rot (23%).

Table 9. Prices (US$/100cc) of some common insecticides used by citrus farmers in the Mekong Delta.

Insecticides/acaricides	Trade name	Application rates (g a.i./ha)	1997	1998
Monocrotophos	Azodrin	500	0.37	Banned
Methyl parathion	Methyl parathion	500	Banned	Banned
Methamidophos	Monitor	700	0.37	Banned
Methidathion	Supracide	400	1.16	1.11
Fenobucarb (BPMC)	Bassa	500	0.26	0.25
Cypermethrin	Ustaad, Sherpa, Cymbush	250	1.04	1.07
Alpha-cypermethrin	Cyper-alpha, Vifast, Fastac	25	0.72	0.74
Fenpropathrin	Danitol	10	0.92	0.95
Imidacloprid	Admire, Confidor	5	3.04	2.92
Sulphur (100 g)	Kumulus	2000	1.20	1.11
Sulphur (100 g)	Microthiol	2000	0.34	0.32
Propargite	Comite	750	2.31	2.14
Fenpyroximate	Ortus	75	1.60	1.48
Hexythiazox	Nissorun	40	2.02	1.87

1U$ = 12,500VND in 1997 and 13,500VND in 1998.

Pesticide use pattern

More than 50% of the sweet orange farmers did not apply fungicides at all, whereas nearly all Tieu mandarin farmers did (Chapter 4). Tieu mandarin is more susceptible to root rot than sweet orange. Besides, the cosmetic appearance of the fruit is very important, because these mandarins are offered to the ancestors during the Vietnamese new year. With the exception of Microthiol, all the popular products used by Tieu mandarin farmers were more expensive than the ones used by sweet orange farmers. Fruit damage by mites or the black spot disease reduces its market value and hence these pests are main targets. These targets were more important for farmers relying on extension (Table 4). Farmers who relied on extension sprayed 43% of their target sprays against mites, compared to 24% by those who had no advice from the extension service. Extension being most important in Dong Thap, Tieu mandarin farmers in this province spent twice as much on fungicides compared to those in Can Tho Province (n=79, Mann-Whitney U=86.0, $P<0.001$).

Analyzing the pesticide use pattern of that group of farmers who applied insecticides or fungicides, farmers relying on media sprayed insecticides more frequently, and those getting advice from the extension applied both insecticide and fungicide sprays more frequently (Table 10). Farmers relying on both extension and media applied 1.26 (4.18 + 3.10 - 8.54) insecticide sprays less compared to those who do not get advice from media or extension at all. Those farmers relying on the extension officer, sprayed insecticides 8.4 more times (0.45 + 7.95) per increase of unit land (1 ha). Farmers with larger orchards typically have less off-farm employment activities, increasing their risk aversion which probably explains their higher pesticide use (Rabb *et al.*, 1972).

Table 10. General linear model parameter estimates for the number of pesticide sprays applied by those citrus farmers using pesticides, Mekong Delta, 1998.

	No. of insecticide sprays n=83		No. of fungicide sprays n=58	
	B[1]	P	B	P
Own experience	4.67	0.001	-	-
Extension	4.18	0.128	3.28	0.065
Media	3.10	0.041	-	-
Extension * Media	-8.54	0.004	-	-
Extension * Area	7.95	0.018	-	-
Area	0.45	0.801	-	-
Omon District	-8.55	<0.001	-	-
Can Tho City	-11.04	<0.001	-	-
Lai Vung District	-	-	6.13	<0.001
Intercept	5.95	0.001	3.51	0.008

[1] B=regression coefficient, P=probability.

Biological control with **Oecophylla smaragdina**

Most insecticides currently applied are detrimental to *O. smaragdina*. Preliminary results indicate that fungicides and foliar fertilizers reduce the ant foraging behaviour, decreasing the efficiency of this biological control agent (Nguyen Thi Thu Cuc, unpublished data). *Oecophylla smaragdina* was abundant in only 25% of the Tieu mandarin orchards mainly because the high pesticide pressure, and in about 75% of the other citrus orchards (Chapter 4). For each of these two groups of orchards, logistic regression models were built for each information source based on all production characteristics. All non-significant factors were eliminated and only significant factors are discussed.

For citrus species other than Tieu mandarin (*n*=72) farmers relying on the media for pesticide advice were best discriminated by the criteria ants (OR=0.26, P=0.027) and Can Tho City (OR=3.55, P=0.025), and those relying on extension were best discriminated by ants (OR=0.26, P=0.077), indicating that those farmers practicing weaver ant husbandry were hardly influenced by media and extension (Figure 2). The presence of ants was not important for farmers' choice towards the other information sources. It could be postulated that because media combined with extension significantly stimulate chemical pest control (Table 9), these information sources have a negative effect on the traditional practice of weaver ant husbandry.

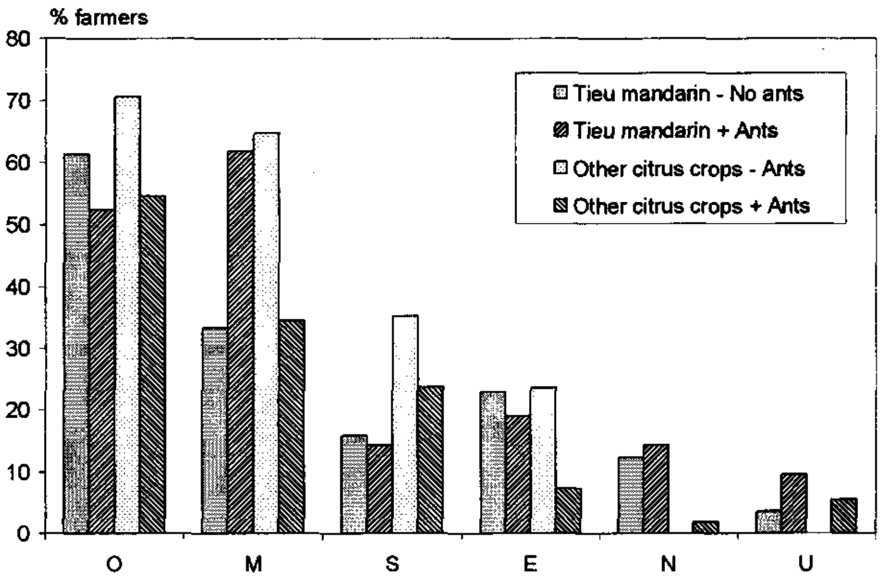

Figure 2. Sources of information influencing farmers' decision-making related to pesticide use in different citrus crops with and without the ant *Oecophylla smaragdina*. O=own experience, M=media, S=pesticide seller, E=extension officer, N=neighbour.

However, when only media were reported to be a major source of pesticide information, this had less impact on the spray pattern than extension alone. Tieu mandarin farmers (*n*=78) with *O. smaragdina* relied more on the media for pesticide advice than those farmers without ants (OR=5.03, P=0.007), but nevertheless used less pesticides and sprayed less frequently than those farmers without ants (Chapter 4). Especially those Tieu mandarin farmers with a higher education level received more advice from the extension staff (OR=1.23, P=0.018). Extension staff sometimes contact farmers through 'advanced farmer clubs', whose members often have a high education level and a strong social position.

Conclusion

Many developing countries still ignore an IPM approach and rely on pesticides for a quick solution to deal with pest problems. This has often been aided by commercial advertisements by chemical companies and by the pesticide sellers, who many times have the ear of the farmer over that of the extension officer (Sharma, 1998). In the Mekong Delta, media were the most important information source for about 40% of the citrus farmers, similar as for mango farmers (Chapter 2), but it was mentioned by less then 10% of the rice farmers (Chung and Dung, 1996). Non-IPM rice farmers relied mainly on the pesticide seller and neighbours for purchasing a product, whereas IPM farmers relied more on the extension staff (Chung and Dung, 1996). Although in citrus the pesticide seller was mentioned by about 20% of the farmers, which was slightly more than the extension officer, the latter had a more significant impact on pest perception and management. The increased knowledge of difficult-to-observe pests acquired through extension activities coincided with increased use of agrochemicals, especially of acaricides and fungicides.

Some of the constraints in promoting IPM in developing countries have been described as 'farmer individualism' and linking of 'progressive farmer' status with expenses on chemical inputs (Sharma, 1998). Both constraints are prevalent in the Mekong Delta. Competition between fruit farmers is strong and it is suggested to positively use this characteristic in the development of IPM, rather than to look at it as a constraint. By the end of 1999, one Tieu mandarin farmer received an award from a local government for producing the highest quality fruit without using pesticides and by practicing weaver ant husbandry. This event was broadcasted on TV. Local initiatives like this could be further stimulated and preferably be combined with institutional and scientific support for biological control (van Lenteren, 1997). The use of *O. smaragdina* has been documented to be more sustainable and without affecting farmers' income (Chapter 4). Because farmers practicing weaver ant husbandry have no forum or platform to exchange ideas among each other, the establishment of 'weaver ant clubs' should receive due consideration. Developing platforms for farmer decision-making has been described as an interesting area of extension research (Röling and van de Fliert, 1994). The second constraint might be even more pronounced for farmers growing high value cash crops such as Tieu mandarin than for farmers cultivating subsistence crops such as rice. In the 'advanced farmer clubs', chemical pest control is indeed often high on the agenda, and in some cases club meetings have been organized by pesticide companies.

Since media and extension were major sources influencing farmers' pest management practices leading to increased use of agrochemicals and reducing the potentials of the ant *O. smaragdina* as a biological control agent, the government has a very important role to play in promoting sustainable agriculture.

References

Adesina, A. A., Johnson, D. E. and Heinrichs, E. A. 1994. Rice pests in the Ivory Coast, West Africa: farmers' perceptions and management strategies. International Journal of Pest Management, 40, 293-299.

Agresti, A. 1990. Categorical Data Analysis. New York, Wiley, pp. 558.

Altieri, M. A. 1993. Ethnoscience and biodiversity: key elements in the design of sustainable pest management systems for small farmers in developing countries. Agriculture, Ecosystems & Environment, 46, 257-272.

Atteh, O. D. 1984. Nigerian farmers' perception of pests and pesticides. Insect Science and Its Application, 5, 213-220.

Burleigh, J. R., Vingnanakulasingham, V., Lalith, W. R. B. and Gonapinuwala, S. 1998. Pattern of pesticide use and pesticide efficacy among chilli growers in the dry zone of NE Sri Lanka (System B): perception vs reality. Agriculture, Ecosystems & Environment, 70, 49-60.

Chung, D. K. and Dung, K. T. 1996. Pest Management in Rice Production in Vietnam: a Socioeconomic Assessment. Hanoi Agricultural University, Hanoi, pp. 67.

Dang, N. P. 1997. Le rôle de la vulgarisation dans la promotion de la culture des arbres fruitiers dans le Delta du Mékong. Mémoire diplôme du Master VOPA. Centre National d'Études Agronomique des Régions Chaudes, Montpellier, pp. 114.

Debrah, S. K., Defoer, T. and Bengaly, M. 1998. Integrating farmers' knowledge, attitude and practices in the development of sustainable Striga control interventions in southern Mali. Netherlands Journal of Agricultural Science, 46, 65-75.

Escalada, M. M. and Heong, K.L. 1993. Communication and implementation of change in crop protection. In: D. J. Chadwick and J. Marsh (eds) Crop Protection and Sustainable Agriculture. Wiley, Chisester, pp. 191-207.

Flint, M. F. 1991. Integrated Pest Management for Citrus. Second Edition. University of California Press, California, 144 pp.

Fujisaka, S. 1992. Will farmer participatory research survive in the International Agricultural Research Centres? Gatekeeper Series No. SA44. International Institute for Environment and Development, London, pp. 3-14.

Hai, T. V., Ba, T. T., Son, P. K., Hai, T. T., Nga, N. T. T., Dung, H. A. and Tri, T. V. 2000. Survey of cultivation practices, pesticide use and pest control in vegetables in Can Tho, Soc Trang and An Giang Province in 1998. Paper presented at the First Joint Workshop on Environmental Conservation and Sustainable Agriculture, Cantho University, January 19-21, 2000. JICA-CTU Project for the improvement of environmental education in agricultural sciences. (in Vietnamese).

Heong, K. L. and Escalada, M. M. 1997. Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, Philippines, 245 pp.

Heong, K. L., Escalada, M. M., Huan, H. and Mai, V. 1998. Use of Communication media in changing rice farmers' pest management in the Mekong Delta, Vietnam. Crop Protection, 17, 413-425.

Kenmore, P. E. 1991. Indonesia's Integrated Pest Management – A model for Asia. FAO Rice IPC Programme. FAO, Manila.

Kenmore, P. E., Litsinger, J. A., Bandong, J. P., Santiago, A. C. and Salac, M. M. 1987. Philippine rice farmers and insecticides: thirty years of growing dependancy and new options for change. In: J. Tait and B. Napompeth (eds) Management of Pests and Pesticides. Farmers' Perceptions and Practices. Westview Press, Boulder, Colorado, pp. 98-108.

Morse, S. and Buhler, W. 1997. Integrated pest management: Ideals and Realities in Developing Countries. Lynne Riener Publishers, London, 171 pp.

Mumford, J. D. and Norton, G. A. 1993. Survey and knowledge acquisition techniques. In: G. A. Norton and J. D. Mumford (eds) Decision Tools for Pest Management. CAB International, Wallingford, pp. 79-88.

Norton, G. A. and Mumford, J. D. 1982. Information gaps in pest management. Proceedings of the International Conference on Plant Protection in the Tropics, pp. 589-597.

Rabb, R. L., Stinner, R. E. and Carlson, G. A. 1972. Ecological principles as a basis for pest management in the agroecosystem. In Concepts of Pest Management. Lecture notes. North Carolina State University, Raleigh, pp. 19-44.

Röling, N., and van de Fliert, E. 1994. Transforming extension for sustainable agriculture: the case of integrated pest management in rice in Indonesia. Agriculture and Human Values, 11, 96-108.

Sharma, M. C. 1998. Integrated pest management in developing countries. RIS Biotechnology and Development Review, 2, 9-18.

van de Fliert, E., 1993. Integrated Pest Management: Farmer Field Schools Generate Sustainable Practices. A Case Study in Central Java Evaluating IPM Training. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 404.

van Huis, A. and Meerman, F. 1997. Can we make IPM work for resource-poor farmers in sub-Saharan Africa? International Journal of Pest Management, 43, 313-320.

van Lenteren, J. C. 1997. From Homo economicus to Homo ecologicus: towards environmentally safe pest control. In: D. Rosen, Tel-Or, E., Hadar, Y. and Chen, Y. (eds) Modern Agriculture and the Environment. Kluwer Academic Publishers, Dordrecht, pp. 17-31.

Van Mele, P. and Phen, T. V. 1999. Utilization and management of orchard ground cover in the Mekong Delta, Vietnam. Proceedings of the 17th Asian-Pacific Weed Science Society Conference, Bangkok, November 22-27, 1999, pp. 296-302.

7. Habitat manipulation for improved control of citrus leafminer and citrus red mite in a mixed orchard-ricefield landscape

Abstract

In the Mekong Delta, Vietnam, the citrus leafminer *Phyllocnistis citrella* (CLM) and the citrus red mite *Panonychus citri* are major pests in both sweet orange (*Citrus sinensis*) and Tieu mandarin (*C. reticulata*). In Tieu mandarin, CLM was reported by farmers to be mainly a problem during the dry season in February-March, when farmers have cleared their canals, adding the sediments on top of the planting beds and as such destroying all the weeds. Irrigation is halted for about two weeks, followed by a period of frequent irrigation to induce flushing and flowering of mandarin. In sweet orange, during the January growth flush induced by irrigation at the beginning of the dry season, CLM populations were not high. During the second flush at the beginning of the rainy season in May-June, following the period of canal clearing in March-April, CLM populations were high. High populations of CLM might be aggrevated after times when the weed flora has been completely destroyed. The citrus red mite was calendar sprayed by Tieu mandarin farmers from flowering until prior to harvest. As citrus farmers only perceive the larger predators such as the weaver ant *Oecophylla smaragdina* and spiders, and have no idea about the existence of predatory mites or parasitoids, they do not know about potential positive attributes of weeds in pest management which sustain populations of natural enemies and their alternative food. IPM training programmes should include learning farmers about predatory mites, as well as to recognize available asteraceous weeds such as *Ageratum conyzoides, Blumea glandulosa* and *Eclipta prostrata* as beneficial weeds. Non-crop trees such as *Spondias dulcis, Mangifera indica, Eucalyptus tereticornis* and *Ceiba pentandra* offer good refuge for the weaver ant. These trees should be further studied for their temporal contribution as food resource for other natural enemies of CLM and mites. Small adjustments of current weed management techniques are suggested to improve availability of pollen and nectar for beneficials at crucial moments in the cropping season, with due respect to implications at the landscape level.

Introduction

In the Mekong Delta, South Vietnam, fruit growing traditionally occurred in home gardens consisting of a mixture of different fruit trees and annual crops, in which animals such as chicken, duck or fish were integrated. However, the rapid population growth in the 1980s in Vietnam (2.2%) has increasingly put pressure on the food supply, prompting the government to stimulate agricultural intensification. Along this line, farmers tend to shift from the home garden system to orchards with less different fruit species. Sweet orange (*Citrus sinensis*) is now mainly grown in oligo- or polycultures. Over the past 10 years, many rice fields have been converted to commercial orchards that are mainly monocultures with Tieu mandarin (*C. reticulata*) or longan (*Dimocarpus longan*). Increased land pressure has had a negative impact on landscape vegetational diversity, decreasing the amount of native vegetation and hence undermining the potential for biological control with the weaver ant *Oecophylla smaragdina* (Formicidae: Hymenoptera) in citrus (Chapter 4).

In many countries, habitat manipulation has increasingly been recognized as an important condition to improve biological control with both exotic and indigenous natural enemies (Altieri and Letourneau, 1982; Andow, 1991; Bugg and Waddington, 1994; Liang and Huang, 1994; Gurr *et al.*, 1998; Altieri and Nicholls, 1999). Not vegetational diversity *per se*, but the type of biodiversity is important for optimal biological control as some non-crop species can be an important resource for insect pests. Therefore, the key problem is to determine which plant species should be maintained or enhanced, and how existing cultural practices can be modified to attain this desired biodiversity. In their review on stability and diversity in ecosystems, van Emden and Williams (1974) stated that the use of herbicides in intensive agriculture reduces floral diversity and can reduce arthropod numbers by half and their biomass by two-thirds. As some weeds can provide important resources to pests, while others may benefit natural enemies, selective removal of weed species may lead to a net benefit (Gurr *et al.*, 1998). Weeds or non-crop plants are more likely to contribute to pest outbreaks when they belong to the same family as the affected crop (Altieri and Letourneau, 1982). The ornamental plant *Murraya paniculata* (L.) Jack, which also belongs to the Rutaceae family, is for instance known to be attractive to the citrus psyllid *Diaphorina citri* (Kuwayama) (Homoptera: Psyllidae), vector of the citrus greening disease (Aubert, 1990).

Thill *et al.* (1991) described in their review paper integrated weed management (IWM) as an important component of IPM. The practice of IWM involves the deliberate selection, integration and implementation of effective weed control measures with due consideration of economic, ecological and sociological consequences. Major beneficial effects of weeds include prevention of soil erosion during heavy rains, retention of soil humidity during the dry season, contribution of organic matter to the soil, provision of food or refuge for beneficial organisms such as predatory mites, spiders, etc., and provision of a source of vegetables or medicines (Akobundu, 1987).

Since only little information is available on weeds in mature orchards in the tropics, and more particularly in Asia (Kazuyoshi and Suzuki, 1981; Sidhu and Bir, 1987; Borthakur and Bhattacharyya, 1993), questions arise whether weeds pose a real problem in this type of agro-ecosystems, or whether the positive attributes of weeds have been evaluated and recognized as in other countries (Altieri and Whitcomb, 1979; Chacon and Gliessman, 1982; Barbosa, 1998; Pickett and Bugg, 1998). In the traditional home garden system in Malaysia, weeds and undergrowth are present all the time and do not affect the productivity of trees such as durian (*Durio zibethinus*) (Othman and Suranant, 1995). In Thailand, weeds often form the ground vegetation under tall fruit trees and are only cleared during the fruiting season to facilitate harvesting. Since the early 1990s the Thai-German 'IPM in Selected Fruit Trees' Project has promoted year-long availability of flowering plants in the orchard to conserve and enhance natural enemies such as predatory mites (Van Mele, 1998b).

In the Mekong Delta, three different stages of knowledge development can be distinguished related to weed management by fruit farmers (T.V. Phen, pers. observation). Initially, farmers had mainly knowledge about those weeds being traditionally used as vegetables or as a source of medicines. Most frequentlly, weeds were weeded by hand or traditional tools. In a second phase, with the wide-scale introduction of herbicides on the market in the 1980s and 1990s, farmers have learned about the negative influence of weeds on crop yield. They shifted away from traditional hand weeding practices and excessively applied broad-spectrum herbicides. Due to recent extension efforts, some farmers in the Mekong Delta have learnt about the beneficial effects of weeds, especially about their role as mulch in conserving soil humidity and reducing erosion (Chuong, 1999).

In this chapter we discuss Vietnamese citrus farmers' insect pest and weed management practices in relation to the citrus leafminer *Phyllocnistis citrella* Stainton (*Gracillariidae: Lepidoptera) and the citrus red mite Panonychus citri* (Mc Gregor) (Tetranychidae: Acarina). These pests are considered in relation to crop phenology and cropping practices. Phenological information about major weed species and the influence of prevailing cropping practices on weed phenology is presented with the aim to map pollen and nectar availability for natural enemies over space and time. Special attention is paid to possible improvements of current weed management practices in the development of more sustainable pest management.

Materials and methods

An extensive survey was conducted from January to April 1998 in the main production areas of the major citrus crops, namely sweet orange and Tieu mandarin. Two major citrus growing provinces were covered in this study, namely Can Tho and Dong Thap. Mean annual rainfall in the study area ranges from 1,300 mm to 1,600 mm. The dry season generally occurs from November/December to April/May. Average elevation of the Mekong Delta is about 0.8 m above sea level and large areas are exposed to flooding during some periods of the year. Most soils of the fruit producing areas in the Mekong Delta are alluvial soils, with a high natural fertility. Production and orchard characteristics are given in Table 1.

Table1. Characteristics of surveyed orchards, Mekong Delta, 1998.

	Sweet orange	Tieu mandarin
No. of farmers interviewed	57	82
Mean orchard size (ha)	0.7[a]	0.6[a]
Mean age orchard (y)	8.4[a]	7.7[a]
Mean estimated yield (tons/ha)	21.9[a]	23.6[a]
Mean crop density (trees/ha)	1064[a]	1043[a]
Converted paddy field (%)	96.5[a]	93.6[a]
Mixed crop (%)	52.5[a]	9.6[b]
O. smaragdina abundant (%)	74.6[a]	28.8[b]
Fish integration (%)	14.0[a]	7.3[a]

[a,b] Different letters in rows indicate a significant difference ($P \leq 0.001$) based on Student's t-test (numerical data) or Pearson χ^2-test (percentages).

Information on the evolution of farmers' weed management practices, as well as on farmers' use of weeds was obtained both through key informant interviews and by synthesizing data from several farmer surveys. Staff from Cantho University and the Mekong Delta Farming Systems Institute, having experience with on-farm surveys for more than 20 years, have been involved in this dynamic information retrieval and synthesizing process. This information is presented as qualitative descriptions. A total of 139 farmers were randomly selected and interviewed about what they perceived to be their major insect, disease and weed problems, and how they managed these pests. A combination of structured and semi-structured open questions was used. Data were encoded and frequency tables made using spreadsheet software programs. SPSS was used for statistical analyses. Students' t-tests and Pearson χ^2-test were conducted to compare orchard characteristics of sweet orange with Tieu mandarin. Information from field observations is presented as unquantified statements.

Relevant literature on conservation biological control related to orchard pest management has been included as well as on pollen and nectar production of major weeds occurring in orchards in the Mekong Delta. Phenological and ecological aspects of these weeds have been retrieved from field observations combined with different sources covering the weed flora of SE Asia.

Results and discussion

Time profile of insect and mite pests in relation to crop phenology

Sweet orange spontaneously flushes at the beginning of the rainy season around April-May, and flowers from June to August. These fruits are harvested mainly in the period February-March (Figure 1a). By irrigating the trees every day or every other day in November-December (early dry season), a second main flush period is created, followed by a second flowering period from January to March. Fruits from these flowers are harvested from July to September. The growth flush induced by irrigation at the beginning of the dry season did not seem to have major problems with citrus leafminer (CLM), whereas the second flush at the beginning of the rainy season in May-June did have problems with CLM (Figure 2a). This outbreak followed the period of canal clearing in March-April.

Tieu mandarin can only yield one crop per year. Trees are irrigated throughout the dry season. After harvest, trees are artificially stimulated to flush in February-March by inducing drought stress for two weeks followed by irrigation and fertilization. Flowers appear in the period March-April and fruits can be harvested the next year in January (Figure 1b). This is just prior to the Vietnamese Tet New Year in February, during which mandarins get a high price on the market. CLM was reported to be most problematic during the leaf-flush period in February-March (Figure 2b). This is also after farmers have cleared their canals, adding the sediments on top of the planting beds and as such destroying all the weeds. These data suggest to test whether destruction of weeds aggravate CLM populations.

Mites were reported by Tieu mandarin farmers to be a problem from March to November (Figure 3). This is actually the whole period of fruit development during which farmers observe the damage symptom. As the planting beds are kept weed free during the last months of the dry season, predatory mites on the ground vegetation are most probably suppressed. Besides, the hot and relatively dry weather is suitable for the development of mite pests, which may explain the fast mite outbreak.

Target sprays against CLM and mites

Sweet orange farmers generally sprayed only about three to four times a year (Chapter 4). CLM and the aphids *Toxoptera aurantii* (Boyer de Fonscolombe) and *T. citricidus* (Kirkaldy) (Homoptera: Aphididae) were the major spray targets in sweet orange (Chapter 5), and CLM was mainly targeted from February to July (Figure 2a). Alpha-cypermethrin and several organophosphorous compounds such as methyl parathion, monocrotophos and methamidophos were mostly used to target these pests. In the scope of this chapter, only data for CLM are presented (Table 2). Surveys conducted in 1994 and 1998 indicated that over this time period and probably much longer, more than 50% of the sweet orange farmers applied these organophosphates, which are highly hazardous for mamals, fish and natural enemies (Chapter 4). Although they also reported mite damage symptoms as a disease, none of them reported the causal agents and treated this pest.

Tieu mandarin farmers, on the other hand, have learned about the existence of citrus red mite, mainly through extension activities and farmer-to-farmer information exchange and consequently targeted this pest, which together with the CLM were among the most important spray targets (Chapter 6). Most of the farmers started spraying against mites from March onwards until December, which is from flowering until harvest (Figure 3). This illustrates the importance farmers attributed to mite pests. CLM was mainly targeted from February to May, from the leaf-flush period until the beginning of the rainy season (Figure 2b). About 15 to 20% of the farmers kept on spraying against leafminers throughout the rainy season, from June to November. Methidathion was the most important insecticide (Table 2), mainly used against CLM, mites and mealybugs (*Planococcus citri*). This organophosphorous product is known to be highly toxic to predatory mites and parasitic wasps of scales (Flint, 1991). In Taiwan, resurgence of citrus red mite occurred following applications of several organophosphates and carbamates (Ho, 1984). The systemic broad-spectrum insecticide imidacloprid is also commonly used against CLM. Mites are, apart from methidathion, also targeted with several acaricidal products such as fenpropathrin, sulphur, propargite and fenpyroximate. Only propargite has been reported to have low toxicity for most natural enemies (Flint, 1991). The combined use of the above mentioned pesticides most likely has a disastrous effect on all beneficial organisms. The fact that in Tieu mandarin only 25% of the orchards have abundant weaver ant populations, compared to 75% of the less intensively sprayed sweet orange orchards (Chapter 4) partly illustrates this. In such intensive cropping systems with high chemical inputs, the role of refuge for benefial organisms is probably even more important as in the less intensively managed sweet orange. Non-crop plants might be a good source for recolonization of orchard trees after spray applications.

Farmers' use of weeds

Initially in the home garden system, farmers had no extensive knowledge about beneficial aspects of weeds, except for those traditionally used as vegetable or as a source of medicine. More recently farmers have learnt about other beneficial characteristics of weeds, especially about their role as mulch (see weed management techniques). As citrus farmers only perceive the larger predators such as weaver ants and spiders, and have no idea about the existence of predatory mites or parasitoids, they are not aware of the possible role of weeds in enhancing beneficials.

Some upland weeds such as *Alternanthera sessilis, Amaranthus viridis* and *Ipomoea batatas* are used as fresh vegetables or in soups. Some plants, besides of being used as vegetable, also have medicinal applications. *Commelina nudiflora* is used as a diuretic and against dysentry among other human diseases. Freshly ground plant material can be applied on the inflammatory areas of bone joints. Leaves of *I. batatas* are used as a laxative. The asteraceous *A. conyzoides* is used against coughs and to heal wounds. Besides the direct benefits to humans, the ground vegetation is also consumed by animals such as chickens or duck.

Common aquatic rice field weeds sometimes infest the canals between the planting beds of orchards. Some of these weeds serve both as food and animal feed (Van Mele, 1998a). The waterspinach, *Ipomoea aquatica*, is consumed by humans or is offered as green forage to pigs, ducks or chickens. Another aquatic weed, *Monochoria vaginalis*, is favorite green forage for ducks. Likewise, the floating fern, *Pistia stratiotes*, is often fed as green forage to pigs and ducks. For tree propagation in nurseries or on-farm, the roots of the water hyacinth *Eichornia crassipes* are used as a rooting substrate for marcotting citrus, longan, durian and sapodilla (*Manilkara zapota*) trees. This vegetative propagation technique results in a superficial root system and is especially important in places where the ground water table is high.

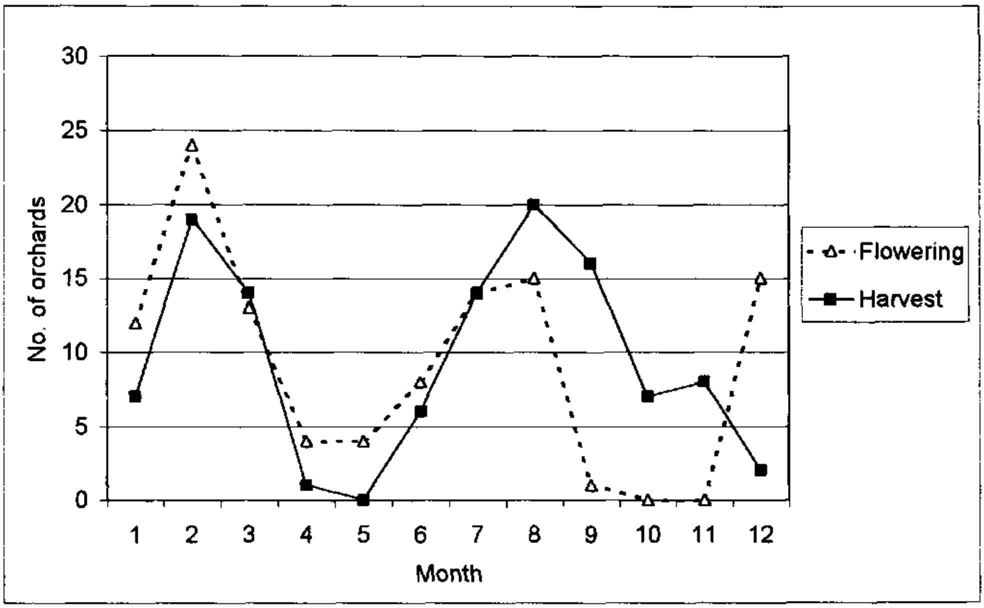

Figure 1a. Flowering and harvest periods of sweet orange (*C. sinensis*) in Can Tho Province, Mekong Delta, Vietnam.

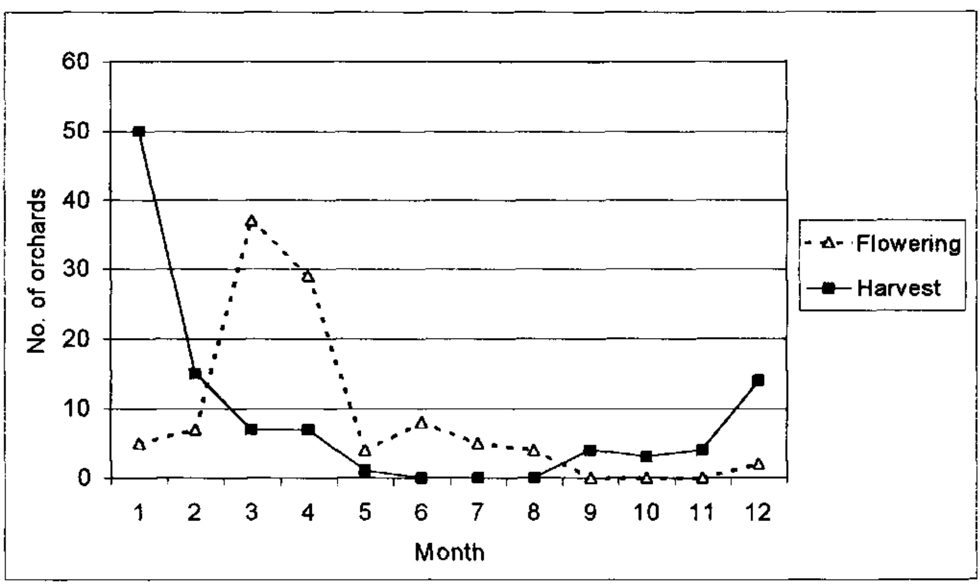

Figure 1b. Flowering and harvest periods of Tieu mandarin (*C. reticulata*), Mekong Delta, Vietnam.

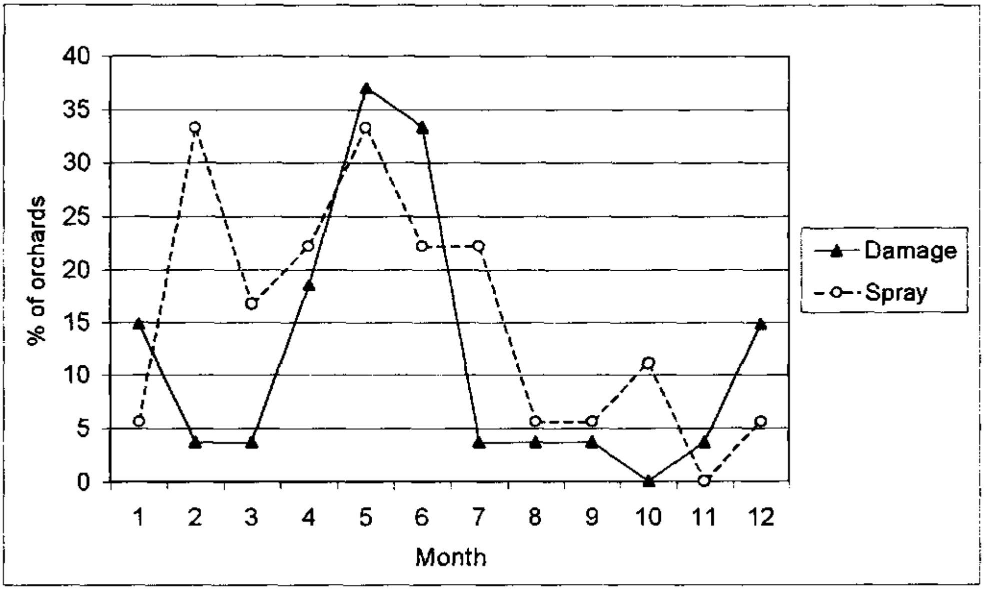

Figure 2a. Peak period of the citrus leafminer (*Phyllocnistis citrella*) according to farmers cultivating sweet orange (*C. sinensis*), and months at which they spray against this target, Mekong Delta, Vietnam.

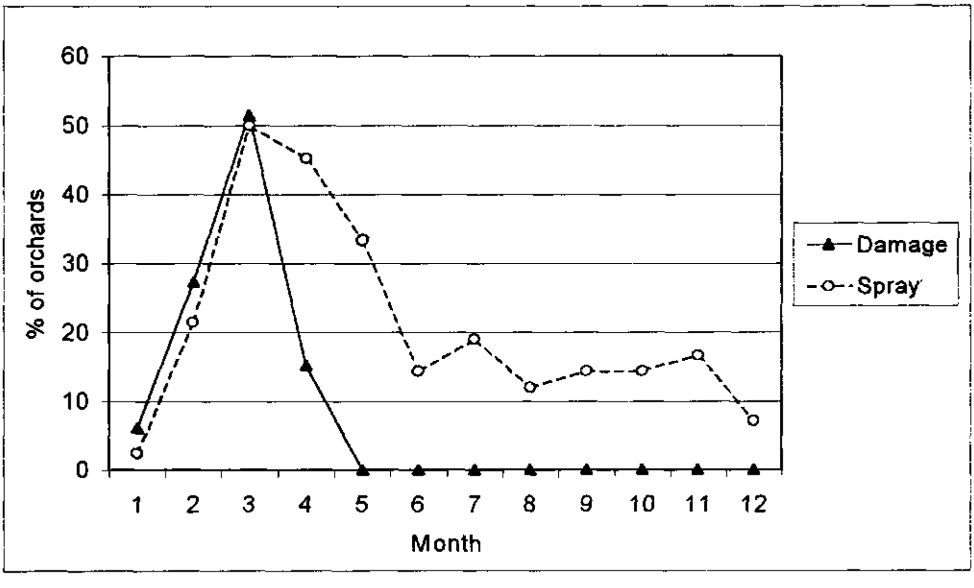

Figure 2b. Peak period of the citrus leafminer (*Phyllocnistis citrella*) according to farmers cultivating Tieu mandarin (*C. reticulata*), and months at which they spray against this target, Mekong Delta, Vietnam.

Table 2. Number of major target sprays (percentage given between brackets) applied against citrus leafminer *Phyllocnistis citrella* and citrus red mite *Panonychus citri* in sweet orange (SO) and Tieu mandarin (TM), Mekong Delta, 1998.

Insecticide/acaricide	WHO toxicity class[1]	Citrus leafminer		Citrus red mite		Total no.[3]	%
		SO	TM	SO	TM		
Organophosphates							
Methidathion	Ib	0 (0.0)	67 (20.4)	2 (66.7)	76 (22.2)	279	17.7
Monocrotophos	Ib	15 (16.0)	19 (5.8)	0 (0.0)	6 (1.8)	158	10.0
Methamidophos	Ib	14 (14.9)	12 (3.7)	1 (33.3)	3 (0.9)	68	4.3
Methyl parathion	Ia	10 (10.6)	0 (0.0)	0 (0.0)	0 (0.0)	57	3.6
Carbamates							
Carbofuran	Ib	0 (0.0)	14 (4.3)	0 (0.0)	0 (0.0)	72	4.6
Methomyl	Ib	0 (0.0)	18 (5.5)	0 (0.0)	10 (2.9)	56	3.7
Pyrethroids							
Alpha-cypermethrin	II	29 (30.9)	3 (0.9)	0 (0.0)	6 (1.8)	137	8.7
Fenpropathrin	II	0 (0.0)	0 (0.0)	0 (0.0)	72 (21.1)	96	6.3
Esfenvalerate	II	1 (1.1)	26 (7.9)	0 (0.0)	8 (2.3)	44	2.9
Acrinathrin	IV	0 (0.0)	0 (0.0)	0 (0.0)	11 (3.2)	11	0.7
Others							
Imidacloprid	II	0 (0.0)	80 (24.4)	0 (0.0)	0 (0.0)	91	6.0
Ethofenprox	IV	14 (14.9)	0 (0.0)	0 (0.0)	0 (0.0)	61	3.9
Sulphur	IV	0 (0.0)	1 (0.3)	0 (0.0)	57 (16.7)	58	3.8
Hexythiazox	IV	0 (0.0)	32 (9.8)	0 (0.0)	20 (5.8)	52	3.4
Propargite	III	0 (0.0)	3 (0.9)	0 (0.0)	41 (12.0)	44	2.9
Fenpyroximate	-	0 (0.0)	0 (0.0)	0 (0.0)	27 (7.9)	27	1.8
Fenvalerate + dimethoate	-	0 (0.0)	30 (9.1)	0 (0.0)	0 (0.0)	37	2.4
Total no.[2]		94	328	3	342	1576	

[1] Ia = extremely hazardous, Ib = highly hazardous, II = moderately hazardous, III = slightly hazardous, IV = unlikely to present acute hazard in normal use, - = unclassified. Source: Anonymous, 1999.
[2] Based on total number of target sprays with all the different insecticides including minor ones not included in table.
[3] Based on all target pests.

Farmers' knowledge of the weed flora

Most of the orchards were converted paddy fields (Table 1). The weed flora, as reported by farmers, therefore mainly consists of rice weeds (Table 3). A long history of rice cultivation has created a typical rice weed seed bank, and the farmers developed an empirical knowledge of these weeds. Generally, farmers have good knowledge about easily observable and important objects (Bentley, 1992). Weeds can be categorized as easily observable. Whether a weed is 'important' as meaning 'of perceived value or harm to the local people' determines the level of taxonomic differentiation and unique classes of knowledge. Weeds with immediate importance as food or medicine were always described up to the species level by farmers. As differentiating up to species level for grasses used as mulch is less important, farmers had for instance one name to describe the different *Ischaemum* spp. (*co mom*). *Cyperus rotundus*, the most noxious sedge is described as *co cu*, while all the other sedges are grouped under one common name, *co lac*. Weeds with no direct importance to farmers were described in very general morphological terms such as 'waxy leave plant' or 'rough leave weed'.

The most frequently mentioned weed was *Commelina* spp. with an overall frequency of 54% (Table 3). Although *C. nudiflora* occurred most frequently, no distinction was made by farmers between this species and *C. benghalensis*. These weeds are actually conserved by farmers to retain soil humidity in the dry season, reduce soil erosion in the rainy season, and to suppress other more competitive weed species. It is also used as medicine as described above. That this weed is not harmful in orchards was long ago described by Popenoe (1920). Most of the weeds mentioned are grasses, probably a heritage from the year after year rice cultivation prior to conversion into orchards.

Scientific considerations about the weed flora

The most frequently noted species are vegetatively propagating perennials (Table 3), and as a result do not produce abundant floral structures (Akobundu, 1987). Pollen production in these plants are therefore more limited compared to annuals. Nearly all weeds reported by farmers were paddy weeds, as described by Moody (1989), with many being lowland weeds. This illustrates the general prevailing moist soil regimes and reflects field history. Differences in occurrence of weeds between the two citrus cropping systems partly reflect the differences in soil type. Tieu mandarin, with a high susceptibility to root rot disease, is often cultivated on sandier soils with a better drainage compared to sweet orange. Therefore, upland weeds such as *Cynodon dactylon* and *Imperata cylindrica* are more important in Tieu mandarin. Typical lowland grasses such as *Leersia hexandra*, *Oryza* spp. and *Sacciolepis interrupta* were more mentioned by farmers growing sweet orange. These weeds typically grow along or within the irrigation canals in the orchard. The last two grasses are intentionnally grown by Tieu mandarin farmers as mulch and are therefore not considered as weeds.

Table 3. Percentage of citrus farmers reporting major weeds, and literature review of plant characteristics important for beneficial enemies.

Scientific name	Family	Sweet orange (%)	Tieu mandarin (%)	Type[1]	Flowering period (month)	Pollination type[2]	Pollen[3]	Nectar[4]	Remarks	Sources[5]
Commelina nudiflora	Commelinaceae	53	68	P (s/v)	07-02	E	-	-	nitrophyl, shade tolerant	1, 4, 6
Ischaemum spp.	Poaceae	49	34	A/P (s/v)	all year	A	+	-		1, 3, 5
Ruellia tuberosa	Acanthaceae	28	32	P (v)	all year	E	-	-		
Brachiaria mutica	Poaceae	19	26	A	10-02	A	+	-		
Leersia hexandra	Poaceae	16	12	P (s/v)	10-02	A	+	-	aquatic	2, 5
Cyperus rotundus	Cyperaceae	11	12	P (v)	10-02	A	-	-		1, 4, 5
Ageratum conyzoides	Asteraceae	33	6	A	all year	E	+	+	life cycle < 2 months	1, 2, 4, 6
Oryza spp.	Poaceae	21	1	A	10-02	A	+	-	aquatic	
Panicum repens	Poaceae	11	7	A	all year	A	+	-	amphibious	2, 4, 6
Sacciolepis interrupta	Poaceae	14	-	P (s/v)	10-02	A	+	-	aquatic	2
Imperata cylindrica	Poaceae	5	13	P (s/v)	10-02	A	+	-	heliophyl	1, 3, 4, 5
Cynodon dactylon	Poaceae	5	12	P (s/v)	10-02	A	+	-	well-drained soils, creeping	1, 3, 5
Digitaria + *Panicum* spp.	Poaceae	4	18	A/P (s/v)	all year	A	+	-		
Eleusine indica	Poaceae	5	5	A/P (s)	all year	A	+	-	flowers after 30 days	1, 4, 5
Echinochloa crus-galli	Poaceae	4	6	A/P (s)	all year	A	+	-		1, 3, 5
Echinochloa colona	Poaceae	2	6	A	all year	A	+	-	short life cycle	1, 3, 5
Paspalum conjugatum	Poaceae	4	4	A/P (s/v)	all year	A	+	-	shade tolerant	1, 6
Alternanthera sessilis	Amaranthaceae	-	9	A/P (s)	all year	A	-	-	amphibious	1
Eclipta prostrata	Asteraceae	-	7	A/P (s)	all year	E	+	+	white flowers	1, 5
Blumea glandulosa	Asteraceae	-	6	A	all year	E	+	+	aromatic, yellow flowers	1, 3
Ipomoea aquatica	Convolvulaceae	-	7	P (s/v)	all year	E	-	-		1, 5

[1] A = annual, P = perennial, s = propagation by seed, v = vegetative propagation; [2] A = anemophilous, E = entomophilous; [3] - = limited pollen production, + = abundant pollen production; [4] - = no nectar production, + = nectar production; [5]Source of information: (1) Radanachaless and Maxwell (1994), (2) Henderson (1951), (3) Henderson (1954), (4) Le Bourgeois and Merlier (1995), (5) Ampong-Nyarko and De Datta (1991), (6) Waterhouse (1994).

Mature orchards have a rather closed canopy, reducing light penetration. Most of the grasses have a C_4 photosynthetic pathway and hence are strongly depressed in shade, reducing both vegetative and floral production (Crowder and Chheda, 1982; Ampong-Nyarko and De Datta, 1991). In mature orchards with a very high planting density, the main source of pollen production is from grasses between the planting beds, along the borders of the canals. This type of spatial design could be classified as a type of border planting (Altieri and Letourneau, 1982). In Californian citrus, various grasses producing windblown pollen are maintained as understorey to hasten the seasonal buildop of phytoseiid predatory mites (Bugg and Waddington, 1994). In Australia, Rhodes grass *Chloris gayana* Kunth is widely allowed to flower in the inter-rows (Smith and Papacek, 1991). Since this grass has a very short life cycle and produces flowers within 3 weeks, year round availability of windblown pollen increases the predatory mite *Amblyseius victoriensis* (Womersley) (Acarina: Phytoseiidae). However, grass-only understorey lacks nectar causing reduced adult longevity of parasitoids like *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) which are widely used for inundative control of lepidopteran pests (Gurr and Wratten, 1999). Nectar is also beneficial for other parasitoids like the encyrtid *Ageniaspis citricola* Logvinovskaya, which is an endemic parasitoid of the citrus leafminer in Vietnam (CABI, 1998).

Because orchards in the Mekong Delta are often interspersed with rice fields, one should consider possible interactions of pests between these two agro-ecosystems. The rice weed *L. hexandra* has for instance been observed to harbor high densities of rice leafhoppers, major vectors of the rice tungro virus (Bottenberg *et al.*, 1990). *Ischaemum rugosum* and *C. rotundus*, on the other hand, are major hosts of this virus (Mallick *et al.*, 1999). Grasses should be controlled before panicle emergence to avoid population build-up of grain-sucking rice hemipterous bugs (Alydidae) and stink bugs (Pentatomidae) (Pathak and Khan, 1994). Weeds are more likely to contribute to pest outbreaks when they belong to the same family as the affected crop (Altieri and Letourneau, 1982) and hence it might be better not to concentrate on the use of grasses as a pollen source in orchards neighbouring paddy fields. Besides, grasses could easily infest paddy fields through seed dispersal by wind or irrigation canals and become weeds.

Under the canopies, C_3 plants such as *Ageratum conyzoides* could become a relatively more important source of pollen. Besides, asteraceous weeds are a good source of floral nectar, which could be important in the adult nutrition of beneficial insects (van Emden and Williams, 1974). Pollen are an important supplementary food source for ladybeetles (Coleoptera: Coccinellidae), and lacewings (Neuroptera: Chrysopidae) seem to prefer composite flowers for their nectar. These insects are important predators of aphids, mealybugs and scales and are more abundant in weed-diversified systems than in weed-free monocrops (Altieri and Letourneau, 1982; Letourneau, 1998; Olkowski and Zhang, 1998). In citrus in the Mekong Delta, nectar producing plants seem to be quite limited with *A. conyzoides* being the most important asteraceous weed.

Over the past years, the importance of orchard ground cover, in particular the availability of asteraceous weeds as a rich source of pollen and nectar to enhance predatory mites, has received more and more emphasis (Waite, 1988; Gravena *et al.*, 1993; Liang and Huang, 1994; Olkowski and Zhang, 1998). The white-coloured down, which covers the whole plant of *A. conyzoides*, provides an ideal oviposition site for predatory mites (Olkowski and Zhang, 1998). Provided predatory mites are present early in the season, control of mite pests is likely (Flint, 1991; Smith *et al.*, 1997). The use of broad-spectrum insecticides destroys this natural balance and triggers the outbreak of mite pests. However, neither citrus nor mango farmers in the Mekong Delta have any knowledge about predatory mites and parasitoids. The concept of predation by *O. smaragdina*, on the other hand, is well known by most farmers (Chapter 4). Weaver ant predation could be used as a starting point to learn farmers about the existence and role of predatory mites. Besides, this generalist predator is compatible with most other beneficial organisms as it does not interfere with existing natural enemies of scales, aphids, mealybugs and mites (Huang and Yang, 1987). IPM training programmes should equally include learning farmers about predatory mites, as well as to recognize asteraceous weeds such as *Ageratum conyzoides*, *Blumea glandulosa*, *Vernonia cinerata* and *Eclipta prostrata* as beneficial weeds.

Current weed management techniques and potentials for modifications

The major weed management technique, hand weeding, was applied significantly more by sweet orange farmers than by Tieu mandarin farmers (Cramer's V=0.20; P=0.018) (Table 4).

Weeding was done by slashing the weeds with a *phan*, by digging up the roots with a machete-like *dao*, or by hand pulling. During the rainy season, hand weeding was done nearly every month in young orchards, and every two-three months in older orchards. Mulching was the second most important weed management technique being practiced in about 70% of the citrus orchards. Herbicides were used by 20% of the sweet orange farmers, and by 30% of the Tieu mandarin farmers. In Tieu mandarin the use of insecticides and fungicides was also highest (Chapter 4; Van Mele and Hai, 1999).

Farmers applying herbicides sprayed on average twice a year, once in the beginning and once at the end of the rainy seaon, and mainly using one product. More than

80% of the farmers applying herbicides used the non-selective, translocated herbicide glyphosate against both annuals and perennials. Because herbicides are applied in the rainy season, run-off to the canals in between the planting beds is highly likely. Toxicity of herbicides to fish has been illustrated, although mortality depends largely on the type of herbicide and fish species tested (Muniyappa *et al.*, 1995). In the Mekong Delta, only one of the farmers rearing fish in the canals of their orchard used herbicides. Glyphosate increases root colonization and infection of peas with *Fusarium solani* (Kawate *et al.*, 1997). This fungus also causes severe root rot problems in citrus in the Mekong Delta. Glyphosate is highly toxic to *Pseudomonas* spp., antagonistic bacteria of soil-borne diseases (Thu *et al.*, 1999). Less than 20% of the farmers applied paraquat against annuals and 2,4-D against both annual and perennial broadleaves. If farmers use herbicides, best would be to apply mixtures of different herbicides and they should be applied in rotation (Kazuyoshi and Suzuki, 1981; Akobundu. 1987). Similar to clean cultivation, a total herbicide treatment of weeds in the orchard leaves the soil prone to erosion. A full cover spray destroys the whole ground vegetation, directly disrupts the soil fauna (Letourneau, 1998) and should be avoided at any time. If herbicides must be used, it would be better to use products such as fenoxaprop (Whip's) and thiobencarb (Saturn), which are more selective against grassy weeds and not harmful to asteraceous weeds (Ampong-Nyarko and De Datta, 1991).

Table 4. Weed management practices of fruit farmers, Mekong Delta, 1998.

	Sweet orange *n*=57	Tieu mandarin *n*=82
Hand weeding (%)	89.4[a]	73.2[b]
Mulching (%)	68.4[a]	65.9[a]
Rotary cutter (%)	5.3[a]	2.4[a]
Herbicides (%)	21.0[a]	30.5[a]
Mean no. of sprays	2.0[a]	2.2[a]
Mean no. of products	1.1[a]	1.2[a]

[a,b] Different letters in rows indicate a significant difference (P≤0.05) based on Student's t-test (numerical data) or Pearson χ^2-test (percentages).

Mulching was primarily done by cutting the weeds in the orchard and leaving them *in situ*, or by cutting and collecting weeds such as *E. crassipes* growing near or in the canals and bringing these to the raised beds of the orchard. Some of the weeds were even intentionally grown by farmers as a source of mulch. In Dong Thap, farmers use one-meter-deep natural depressions (*lung*) in paddy fields to grow *ex situ* 'mulch weeds', such as *Oryza rufipogon*, *Ischaemum indicum* and *Sacciolepis interrupta*. These are grasses with a fast developing above ground biomass. Rice straw and husks were used in some cases only, despite its high availability in the region. Many competing applications of these natural resources make them more difficult to purchase (Van Mele, 1998a). Experiments with different mulches in guava orchards in India indicated that rice husks suppressed weeds most efficiently, resulting in higher yields (Borthakur and Bhattacharyya, 1993). Mulching with rice straw or slashed weeds is also common practice to reduce the abundance of annual weeds in Thai orchards (Suwanarak and Supasilapa, 1990), while geese are often used to graze *C. rotundus*. In the Mekong Delta of Vietnam, only few farmers mentioned chickens and duck to graze in their orchard. In a pineapple intercrop under coconut in Sri Lanka, mulching with coconut coir dust significantly suppressed *Ageratum conyzoides* and *C. rotundus*, while the incidence of *C. nudiflora* was enhanced (Van Mele *et al.*, 1996). To conserve *A. conyzoides*, it might therefore be better to restrict mulches to the rooting zone of the tree only. Better even would be to first compost the weeds before applying them around the tree base. In aged compost, effectiveness of the biocontrol fungus *Trichoderma* spp., which suppresses soilborne diseases is increased (Neher and Barbercheck, 1999).

A common practice of fruit farmers in the Mekong Delta is to remove the sediments of canals after fruits have been harvested. This might be done every year or every second year, depending on the amount of sediment deposited. As such, the level of the planting beds can be maintained over the years and the canals are kept clean for irrigation or fish culture. The alluvial sediments are spread over the planting beds and consequently weeds are completely covered. New weeds emerge only after one month. It is surprising that only a few farmers described this practice as a type of mulching. This practice of canal clearing has both its positive and negative aspects. Large amounts of organic matter consisting of the complete weed biomass is incorporated. This increases soil stability. Besides, with the sediments abundant nutrients are provided to the soil and consequently the trees develop new roots in the upper soil layer.

However, this practice could have a negative effect on the soil fauna and destroys the complete weed flora during a period that might be crucial for many beneficial insects, mites and spiders. After all, this practice is a way of clean cultivation that drastically reduces vegetational biodiversity and deprives beneficial organisms from refuge and food. Any kind of agricultural disturbance can alter the diversity of an ecosystem directly by affecting survivorship of individuals or indirectly by changing resource levels (Neher and Barbercheck, 1999).

In China, *A. conyzoides* is cultivated as ground cover since it is the most important pollen and nectar producing plant, enhancing predatory mites (Liang and Huang, 1994). Asteraceous plants are protandrous. Pollen produced in the corolla are released before the stigmas of the same flower become receptive. Later on, pollen are pressed upwards by the emerging stigma, making all the pollen become available on top of the flower heads. This mechanism is called secondary pollen presentation and makes this resource easily available for predatory mites. In the Mekong Delta, mites were reported to be a problem from March onwards (Figure 3). By cleaning the canals in February-March, it is very well possible that available predatory mites are suppressed because of food deprivation, causing a mite outbreak.

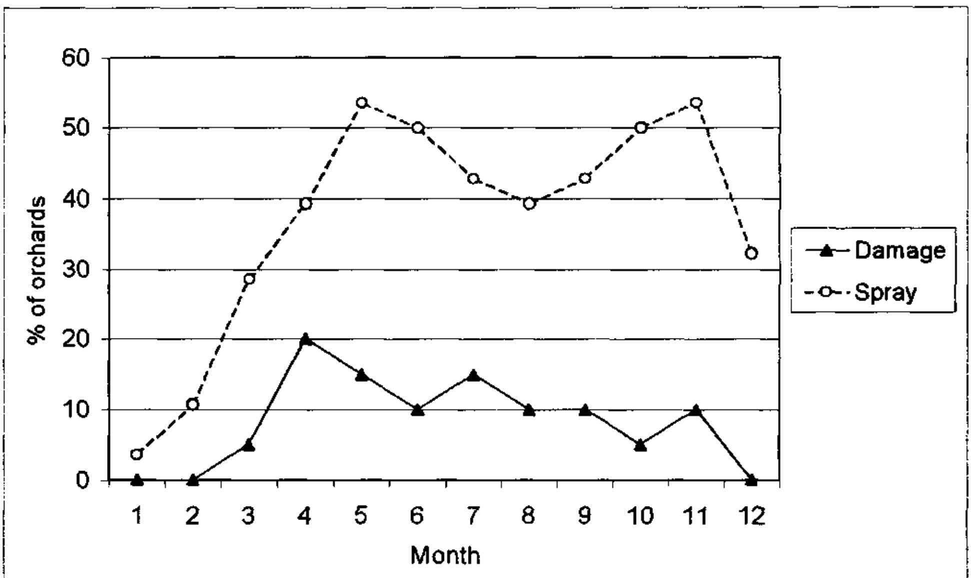

Figure 3. Peak period of citrus red mite (*Panonychus citri*) according to farmers cultivating Tieu mandarin (*C. reticulata*), and months at which they spray against this target, Mekong Delta, Vietnam.

Small modifications of farmer practices have better chance of being adopted by farmers (Matteson *et al.*, 1984). Some minor changes could make the practice of canal clearing a more compatible and even beneficial practice within an IPM programme. One alternative might be that farmers apply the sediments only around the tree base, leaving the rest of the weeds untouched, a similar approach as with ring weeding. If weeds do become a problem, mechanical weeding or hand weeding could be practiced in alternate rows. A part of the ground vegetation should be conserved, especially in Tieu mandarin cropping systems where non-crop trees are scarce. Cut weeds can serve as mulch, as is already being practiced now, and should preferably be put around the tree base only. Ideally, weeds should be composted first. Another alternative would be that farmers clear their canals annually and apply the sediments on alternate planting beds every other year. In this way, the level of the beds is maintained over the years, and weeds remain available to natural enemies during the whole year.

Agro-ecological considerations of non-crop trees

Traditionally, citrus farmers in the Mekong Delta use the weaver ant *O. smaragdina* as a biological agent to control several major insect pests (Chapters 4 and 5). Farmers taking care of these ants apply significantly less insecticides and fungicides (Chapter 4). No difference was observed regarding their weed management practices, probably because these ants have their nests in tree canopies and patrol the orchard by using natural or artificial 'ant highways', consisting of branches, bamboo poles or ropes connecting different tree canopies. Apart from flowering weeds, availability of flowering non-crop trees within or around the orchard is very important, not only as nesting sites for the weaver ant *O. smaragdina*, but also as a nectar and pollen source for other beneficials (Olkowski and Zhang, 1998). The majority of the sweet orange orchards are polycultures *sensu lato* consisting of a mixture of different *Citrus* species, non-crop trees and ground vegetation, whereas Tieu mandarin is not mixed with other trees and only has ground cover. This implies that after each weeding practice, Tieu mandarin is converted into a monocrop *sensu stricto*. The non-crop trees in sweet orange therefore not only give the agro-ecosystem a higher structural diversity, there is also a better continuity of food supply over time. Some trees commonly colonized by *O. smaragdina* are *Annona glabra* (Annonaceae), which grows along the canals between the planting beds, *Spondias dulcis* and *Mangifera indica* (Anacardiaceae), which provide fruits and shade as an intercrop in many citrus orchards. Also trees such as *Eucalyptus tereticornis* and *Ceiba pentandra* (Bombacaceae) offer good potential for weaver ant husbandry among some other sociological and economic functions (Chapter 4; Van Mele, 1999). Diversity *per se* is not important in ecosystems, but the components of diversity are (van Emden and Williams, 1974). Some non-crop vegetation can indeed host pest species (Gurr *et al.*, 1998). Those non-crop trees colonized by ants should be studied for their temporal contribution as food resource, or as alternate host plants of pests.

Close proximity of non-crop vegetation was the main factor influencing dispersal of *O. smaragdina* in cashew orchards in northern Australia (Peng *et al.*, 1998) and in coconut plantations in the Solomon Islands (Greenslade, 1971). Windbreaks of *Eucalyptus torelliana* F. Muell. acted as reservoirs of the predatory mite *A. victoriensis* for nearby blocks of citrus in Australia (Smith and Papacek, 1991). Phytoseiids use air currents as a major means of dispersal. The underleaf surface of *E. torelliana* is quite hairy and the hairs are popular oviposition sites for *A. victoriensis* and also possibly act as a trap for windblown pollen.

It is recommended to further study the potential of above mentioned tree species growing within or around citrus orchards in the Mekong Delta for provision of food for predatory mites and other beneficial organisms.

Conclusion

The use of highly toxic pesticides in orchards in the Mekong Delta deserves special attention since it affects human health, fish production, and natural enemies among other aspects of environmental degradation. The conservation of natural enemies through habitat manipulation has great potential in the diverse orchard-paddy field landscape, and requires a holistic approach. The fact that citrus farmers keep their orchard weed-free during a period which is crucial for beneficial organisms, clearly points out that they are not aware of the possible role of weeds in enhancing beneficials. Farmers should be trained to conserve asteraceous weeds like *Ageratum conyzoides* as an important pollen source for predatory mites. Since all the citrus growers know about the predatory behaviour of the weaver ant *Oecophylla smaragdina*, this concept could be used to train farmers about the role of predatory mites.

References

Akobundu, I. O. 1987. Weed Science in the Tropics. John Wiley & Sons Ltd., New York, 522 pp.

Altieri, M. A. and Letourneau, D. K. 1982. Vegetation management and biological control in agroecosystems. Crop Protection, 1, 405-430.

Altieri, M. A. and Nicholls, C. I. 1999. Biodiversity, Ecosystem Function, and Insect Pest Management in Agricultural Systems. In: W. W. Collins and C. O. Qualset (eds) Biodiversity in Agroecosystems. CRC Press, Boca Raton, pp. 69-84.

Altieri, M. A. and Whitcomb, W. H. 1979. The potential use of weeds in the manipulation of beneficial insects. Hortscience, 14, 12-18.

Ampong-Nyarko, K. and De Datta, S. K. 1991. A Handbook for Weed Control in Rice. IRRI, Manila, pp. 113.

Andow, D. A. 1991. Vegetational diversity and arthropod population response. Annual Review of Entomology, 36, 561-586.

Anonymous 1999. Database on Pesticides and the Environment. ESCAP/CIRAD/EU. http://www.fadinap.com/pesticide.

Aubert, B. 1990. Prospects for citriculture in Southeast Asia by the year 2000. FAO Plant Protection Bulletin, 38, 151-173.

Bentley, J. W. 1992. The epistemology of plant protection: Honduran campesino knowledge of pests and natural enemies. In: R.W. Gibson and A. Sweetmore (eds) Proceedings of a Seminar on Crop Protection for Resource-Poor Farmers. CTA/NRI, pp. 107-118.

Borthakur, P. K. and Bhattacharyya, R. K. 1993. Effect of mulches on controlling weeds in guava orchards. Proc. Int. Symp. Indian Soc. Weed Sci., Hisar, Vol. III, pp. 219-221.

Bottenberg, H., Litsinger, J. A., Barrion, A. T. and Kenmore, P. E. 1990. Presence of tungro vectors and their natural enemies in different rice habitats in Malaysia. Agriculture, Ecosystems & Environment, 31, 1-15.

Bugg, R. L. and Waddington, C. 1994. Using cover crops to manage arthropod pests of orchards: a review. Agriculture, Ecosystems & Environment, 50, 11-28.

CABI 1998. Crop Protection Compendium – CDRom Module 1. CAB International, Wallingford, U.K.

Chacon, J. C. and Gliessman, S. R. 1982. Use of the 'non-weed' concept in traditional tropical agroecosystems of southeastern Mexico. Agro-Ecosystems, 8, 1-11.

Chuong, D. V. 1999. Some cultural practices necessary in orchard cultivation. In: Van Mele, P. and Huynh, N. V. (eds) Proceedings of the Second Symposium on Fruit Production in the Mekong Delta Focusing on IPM. Cantho University, Can Tho, Vietnam, pp. 159-160.

Crowder, L. V. and Chheda, H. R. 1982. Tropical Grassland Husbandry. Longman, New York, 562 pp.

Flint, M. F. 1991. Integrated Pest Management for Citrus. Second Edition. University of California, California, 144 pp.

Gravena, S., Coletti, A. and Yamamoto, P. T. 1993. Influence of green cover with *Ageratum conyzoides* and *Eupatorium pauciflorum* on predatory and phytophagous mites. Bulletin OILB-SROP, 16(7), 104-114.

Greenslade, P. J. M. 1971. Interspecific competition and frequency changes among ants in Solomon Islands coconut plantations. Journal of Applied Ecology, 8, 323-349.

Gurr, G. M. and Wratten, S. D. 1999. 'Integrated Biological Control': a proposal for enhancing success in biological control. International Journal of Pest Management, 45, 81-84.

Gurr, G. M., van Emden, H. F. and Wratten, S. D. 1998. Habitat manipulation and natural enemy efficiency: implications for the control of pests. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 155-183.

Henderson, M. R. 1951. Malayan Wild Flowers. Dicotyledons. Malayan Nature Society, Kuala Lumpur.

Henderson, M. R. 1954. Malayan Wild Flowers. Monocotyledons. Malayan Nature Society, Kuala Lumpur.

Ho, K. Y. 1984. Observation on resurgence of citrus red mite, *Panonychus citri* (Mc Gregor) following pesticide applications. Plant Protection Bulletin Taiwan, 26, 99-108.

Huang, H. T. and Yang, P. 1987. The ancient cultured citrus ant. Bioscience, 37, 665-671.

Kawate, M. K., Colwell, S. G., Ogg, A. G. Jr. and Kraft, J. M. 1997. Effect of glyphosate-treated henbit (*Lamium amplexicaule*) and downy brome (*Bromus tectorum*) on *Fusarium solani* f.sp. *pisi* and *Pythium ultimum*. Weed Science, 45, 739-743

Kazuyoshi, H. and Suzuki, K. 1981. Weeds in citrus orchards and their control in Japan. In: Weeds and Weed Control in Asia. Taipei, Food & Fertilizer Technology Center, pp. 211-215.

Le Bourgeois, T. and Merlier, H. 1995. Adventrop. Les Adventices d'Afrique Soudano-Sahelien. CIRAD-CA, Montpellier, 637 pp.

Letourneau, D. K. 1998. Conservation biology: lessons for conserving natural enemies. In: P. Barbosa (ed.) *Conservation Biological Control*. Academic Press, New York, pp. 9-38.

Liang, W. G. and Huang, M. D. 1994. Influence of citrus orchard ground cover plants on arthropod communities in China: a review. Agriculture, Ecosystems & Environment, 50, 29-37.

Mallick, S. C., Chowdhury, A. K. and Pal, D. 1999. *Ischaemum rugosum* - a potential alternate host of rice tungro viruses in West Bengal. International Rice Research Notes, 24, 28-29.

Matteson, P. C., Altieri, M. A. and Gagné, W. C. 1984. Modification of small farmer practices for better pest management. Annual Review of Entomology, 29, 383-402.

Moody, K. 1989. Weeds Reported in Rice in South and Southeast Asia. IRRI, Manila, 442 pp.

Muniyappa, T. V., Manjunatha, V., Babu, V. S. and Shivakumar, H. R. 1995. Efficacy of post emergent herbicides on control of water hyacinth (*Eichhornia crassipes* Mart.) and their effect on fishes. World Weeds, 2, 117-121.

Neher, D.A., Barbercheck, M.E. 1999. Diversity and function of soil mesofauna. In: W. W. Collins and C. O. Qualset (eds) Biodiversity in Agroecosystems. CRC Press, Boca Raton, pp. 27-47.

Olkowski, W. and Zhang, A. 1998. Habitat management for biological control, examples from China. In: C. H. Pickett and R. L. Bugg (eds) Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, California, pp. 255-270.

Othman, Y. and Suranant, S. 1995. The Production of Economic Fruits in South-East Asia. Oxford University Press, New York, 419 pp.

Pathak, M. D. and Khan, Z. R. 1994. Insect Pests of Rice. IRRI, Manila, pp. 89.

Peng, R. K., Christian, K. and Gibb, K. 1998. The effect of non-crop vegetation on the insect pests and their natural enemies in cashew (*Anacardium occidentale* L.) plantations. Plant Protection Quarterly, 13, 16-20.

Pickett, C. H. and Bugg, R. L. 1998. Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, California, pp. 433.

Popenoe, W. 1920. Manual of Tropical and Subtropical Fruits. Mac Millan Co., New York.

Radanachaless, T. and Maxwell, J. F. 1994. Weeds of Soybean Fields in Thailand. Multiple Cropping Center, Chiang Mai, pp. 408.

Sidhu, M. and Bir, S. 1987. Weed flora of orchards in Patiala district. Indian Journal of Weed Sciience, 19, 9-19.

Smith, D. and Papacek, D. 1991. Studies of the predatory mite *Amblyseius victoriensis* (Acarina: Phytoseiidae) in citrus orchards in south-east Queensland: control of *Tegolophus australis* and *Phyllocoptruta oleivora* (Acarina: Eriophyidae), effect of pesticides, alternative host plants and augmentative release. Experimental & Applied Acarology, 12, 195-217.

Smith, D., Beattie, G. A. C. and Broadly, R. 1997. Citrus pests and their natural enemies. Integrated pest management in Australia. Queensland Dept. of Primary Industries, pp. 272.

Suwanarak, K. and Supasilapa, S. 1990. Weed management in fruit crops in Thailand. Proceedings Technical Conference on IPM in Selected Fruit Trees. Bangkok, DOA and DOAE, pp. 29-44.

Thill, D. C., Lish, J.M., Callihan, R. H. and Bechinski, E. J. 1991. Integrated weed management-a component of integrated pest management: a critical review. Weed Technology, 5, 648-656.

Thu, L. T. M., Mai, T. T. N., Phu, L. C. and Kim, P. V. 1999. Effect of pesticides on soil bacteria, antagonistic agents to *Rhizoctonia solani* and on cellulose decomposing *Trichoderma* collected from the Mekong Delta. In: Cantho University Report 1997-1999, pp. 26-31.

van Emden, H. F. and Williams, G. F. 1974. Insect stability and diversity in agro-ecosystems. Annual Review of Entomology, 19, 455-475.

Van Mele, P. 1998a. Alternative uses of rice by-products in Vietnam. Humus News, 14, 2-3.

Van Mele, P. 1998b. Integrated Fruit Production of Mango and Durian in the Eastern Region of Thailand. Vietnamese-Belgian IPM Project Technical Report N°2, 22 pp.

Van Mele, P. 1999. Living fences around orchards in southern Viet Nam. Non-Wood News, 6, 48-49.

Van Mele, P. and Hai, T. V. 1999. Pesticide Use in Orchards in the Mekong Delta of Vietnam. In: Proceedings of the 5th International Conference on Plant Protection in the Tropics, Kuala Lumpur, March 15-18th, 1999, pp. 529-533.

Van Mele, P., Dekens, E. and Gunathileke, H. A. J. 1996. Effect of coir dust mulching on weed incidence in a pineapple intercrop under coconut in Sri Lanka. Mededelingen Faculteit Landbouwwetenschappen Universiteit Gent, 61, 1175-1180.

Waite, G.K. 1988. Integrated control of *Tetranychus urticae* in strawberries in south-east Queensland. Experimental & Applied Acarology, 5, 23-32.

Waterhouse, D. F. 1994. Biological Control of Weeds: Southeast Asian Prospects. ACIAR, Canberra, 548 pp.

8. Discussion

Bentley and Andrews (1991) stated that applied studies of farmers' knowledge, with a narrow, less or non-comparative focus, are of limited use to scholars of ethnoscience and formal knowledge systems. In this thesis I have tried to assess the possibilities for integrating traditional knowledge, and more broadly farmers' knowledge in pest management, into integrated fruit production systems, based on aspects of approaches of Rapid Appraisal of Agricultural Knowledge Systems (RAAKS). This has been carried out by conducting interviews with several stakeholders such as farmers, extensionists, researchers, pesticide sellers and staff from the Ministry of Agriculture and Rural Development, among which the Plant Protection Department (PPD). These interviews have been complemented with several on-farm experiments. The different aspects influencing farmers' knowledge, perceptions and practices (KPP) which are discussed are given in a comprehensive, schematic diagram (Figure 8). Because the hypotheses formulated in section 1.5. have been covered in different chapters dealing with one or more of the studied fruit cropping systems, it has been opted to discuss obtained results by using this scheme, rather than dealing with the hypotheses one by one.

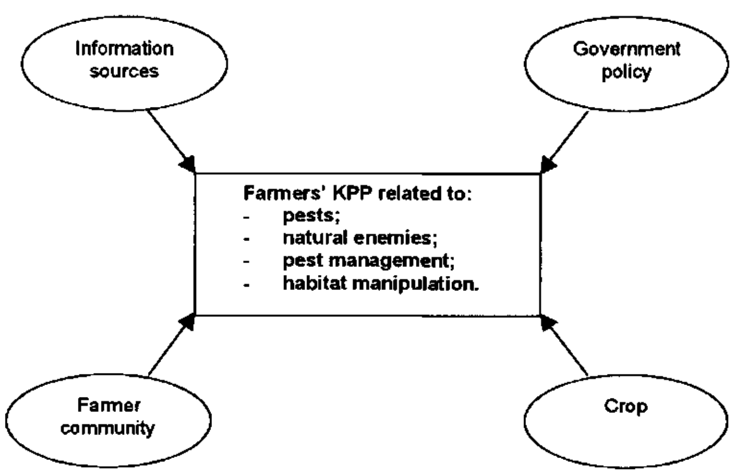

Figure 8. Main factors determining farmers' knowledge, perceptions and practices (KPP) in pest management within a given agro-ecosystem.

8.1. Pests

During our study, farmers were asked which pest problems they faced. Their answers were recorded and cross-checked in the field whenever possible. However, for three major reasons it was often impossible to evaluate farmers' pest recognition abilities. First, there was a time constraint. For reasons of accessability all the farmers were visited during the dry season (November-April), when most perennial fruit crops are in the flowering or fruiting stage depending on the climate, the fruit species and variety, and managerial practices such as floral induction. Therefore, only pests specific to those phenological stages of the trees could be encountered. Second, in many cases farmers had sprayed their orchard prior to our visit so that often no insects could be observed. Third, photos of all the different pests, which could be used to display to farmers, were not available at the begining of the project. Instead, farmers were asked to describe the pest and damage symptoms whenever necessary. Project staff were accustomed to the local terminology used by the farmers having been involved in several farmer surveys before.

For the identification, assessment and management of pests, information is important to farmers. Whether and how they use it depends on socio-economic factors such as the age of the farmer, their level of education, their hierarchical status in the village, the availability of radio or TV, the production region, the government policy and the type of crop grown. Literacy in Vietnam is generally high. From the nearly 500 fruit farmers interviewed during 1997-1998, more than 95% had ever attended school. However, because farmer training in fruit production has started only recently, less than 25% had ever followed an extension course (Chapter 1). Training in crop protection has been limited to chemical control (Chapter 6). Nearly half of those farmers who had ever attended an extension course explained that they relied on the extension officer for advice on pesticide use. In general, extension focused on farmers with a relatively high educational level. Individual orchards are hardly visited because of the extension staff's high work load. More often they contact farmers through 'advanced farmer clubs', whose members have a high education level and a strong social position, reflected in them cultivating a relatively large area under fruit crops (Dang, 1997; Chapter 6).

The ease of observation is an important aspect contributing to farmers' knowledge and perception of pests (Bentley, 1992). Conspicuous pests or damage symptoms are often considered more important. Rice farmers usually overreact to leaf-feeding insects, since they strongly believe that these pests reduce yield (Heong *et al.*, 1994; de Kraker, 1996; Mai *et al.*, 1997; Heong and Escalada, 1998). However, for tropical fruit crops no literature exists on the impact of leaf-feeding insects on yield loss. The injury of these pests is highly visible, causing fruit farmers to target them with pesticides. The majority of mango farmers reporting leaf-feeding caterpillars and the leaf webber *Orthaga* sp. targeted these pests with organophosphates and pyrethroids (Chapter 2). Leaf-damaging pests were also targeted by sapodilla farmers (Chapter 3) and citrus farmers (Chapters 5 and 6).

The ease of observing pests in orchards is highly determined by cultivation practices influencing the size of the trees. As opposed to cultivation systems in Thailand where the production of well-formed trees is an important aspect of integrated fruit production (Othman and Suranant, 1995; Van Mele, 1998), formation of durian and mango trees by pruning and trimming is never practiced in Vietnam. As a consequence, these trees often grow 8 m high or more, hampering pest monitoring, and increasing the importance of broadening farmer training from integrated pest management (IPM) to integrated crop management (ICM). About 14% of the mango farmers in the Mekong Delta, none of which had ever attended an extension course, reported high yield losses due to the fruit fly *Bactrocera dorsalis*. However, during field studies from 1994 to 1996, fruit flies occurred in fewer than 2% of the mango orchards, and therefore should not be considered a serious problem in mango (Cuc *et al.*, 1998). Those farmers mentioning fruit flies have confused its damage symptom with that caused by the very common mango seed borer *Deanolis albizonalis*. In the mid 1990s, confusion between these two pests or damage symptoms was very common, but through media and extension activities, this situation has in general improved (Nguyen Thi Thu Cuc, pers. comm., 1999). In 1998, about 90% of the farmers considered the seed borer as a problem. Waterhouse (1998) found it remarkable that worldwide there are so very few references to the mango seed borer and postulated that its damage is commonly attributed to other causes.

The type of pest species and their perceived severity partly depends on the type of crop cultivated and the producers' risk considerations. Although similar insect pests occur in the different citrus cropping systems, sweet orange farmers generally perceived pest problems as less severe than Tieu mandarin farmers. Oranges have a yellow-green peel (the typical orange colour only appears after the fruit is exposed to cold temperatures at night, which never happens in the Mekong Delta), whereas Tieu mandarins are bright orange. Besides, Tieu mandarin is harvested around the Vietnamese New Year, making this fruit particularly interesting for offerings to the ancestors. Due to this socio-cultural situation Tieu mandarin is an economically more profitable crop than sweet orange (Chapter 4), its market value being three to five times higher than for sweet orange, so farmers attach importance to the cosmetic appearance of the fruit. This decreases the economic threshold and indeed both insecticide and fungicide use was higher in Tieu mandarin compared to sweet orange (Chapter 4). In Dong Thap, due to pesticide promotion campaigns by extension and media, pesticide use further increased (Chapter 6), causing problems with pest resurgence and pest resistance. Therefore, only in Dong Thap Tieu mandarin farmers reported and/or targeted thrips, mites and scales (Chapters 5 and 6).

Farmers' recognition of a pest species, and especially of those that are difficult to observe, largely depends on the available information sources. Our data illustrate that fruit farmers in the Mekong Delta have learnt about the existence of difficult-to-observe pests through pesticide advertising campaigns or farmer-to-farmer promotion of pesticide products (Chapter 6). For example, thrips were only reported by Tieu mandarin farmers who relied on the extension or media for their pesticide advice. The citrus red mite *Panonychus citri* was mainly mentioned as a pest problem when the neighbour or the extension was an important pesticide information source. The symptoms caused by mites, on the other hand, were reported as a disease mainly by citrus farmers depending on the media. At regular intervals at the beginning of each fruiting season, a video dealing with mites is broadcasted during the agricultural programme on TV. Although pictures of mites are displayed, this seemingly does not contribute to the farmers' knowledge of the organism (Ochou *et al.*, 1998). At the time of our survey, some extension activities with field visits and the provision of hand lenses had been organized to assist farmers in recognizing mites. However, only a few farmers had hand lenses, and still 75% of the Tieu mandarin farmers in Dong Thap mentioned mites in their orchard. Most farmers have probably never observed the very small mites, and just sprayed their orchard prophylacticly based on advice from the Extension Service or media. Whether Tieu mandarin farmers actually know mites, should be further investigated by confronting them with life samples.

The influence of the Extension Service on farmers' knowledge, perceptions and practices depends largely on the region (Chapters 2, 3 and 6). Despite the fact that the citrus greening disease has been the major topic of fruit extension activities and leaflets in Can Tho Province since 1994, only six farmers reported its vector, the psyllid *Diaphorina citri*, as a pest problem (Chapter 6). In Dong Thap, where the greening disease has not been covered by extension, none of the farmers reported psyllids. Seemingly, farmers' perception has not changed since 1992, when Whittle wrote that although *D. citri* was observed in Vietnam, citrus growers did not regard it as a spray target.

In Can Tho, about 90% of the sweet orange farmers and 70% of the Tieu mandarin farmers reported greening as the most severe citrus disease. In Dong Thap, on the other hand, less than 30% of the Tieu mandarin orchards had these problems. Citrus farmers in Can Tho, contrary to most citrus farmers transferring their orchards to another fruit crop after severe infestation, prefer to stick to citrus cultivation because they have a long tradition in doing so. They cut the dead trees and replant with the same or a different citrus variety. Besides of being spread by the homopterous vector, the greening disease is distributed through vegetative propagation (Aubert, 1990). Establishing young trees with strong taproots is more of a drawback than an advantage in areas with a permanent high water table as in the Mekong Delta, and therefore about 65% of all the citrus trees in this region have been propagated by air layering, often done by the farmers themselves. This has contributed to the rapid spread of the greening disease. It shows that despite their long experience, farmers have no knowledge about this rather recently introduced disease and how it is spread or controlled.

There is a big difference in farmers reporting greening infestation in the two neighbouring provinces. Because extension activities in Can Tho have focused on this disease, farmers in this province probably have incorporated this information resulting in nearly all farmers mentioning this as their problem. Norton and Mumford (1983) suggested that farmers' perceptions of pest problems might be derived from their perceptions of what they regard as the key pest problem in their region.

8.2. Natural enemies

8.2.1. General

There is a major difference between rice farmers and fruit farmers regarding farmer-to-farmer information exchange. In rice, the majority of the IPM farmers learnt about natural enemies from IPM trainers, whereas the majority of untrained farmers in the Mekong Delta have learnt about this from their neighbours or relatives (Chung and Dung, 1996). The rice ecosystem is an open habitat where farmers can easily observe other farmers' management practices, facilitating information exchange. Fruit farmers, on the other hand, have only learnt about natural enemies by observing their own orchard. Orchards are more closed habitats and farmers seemingly are rather reluctant to transfer their knowledge. The fact that relevant information hardly spread among citrus farmers was also observed by van Schoubroeck (1999). The lack of IPM trainers or an appropriate forum for fruit farmers will be discussed in a later section.

The fact that fruit farmers are entirely self-educated regarding natural enemies explains why they only perceived larger predatory species, and were unaware of the existence of parasitoids. Bentley (1992) classified the area of knowledge of items which are both conspicuous and important to farmers as an area where scientists can learn from farmers. Social insects such as predatory ants belong to this area, although scientific work could substantially contribute to further improving the knowledge and use of these predators.

In the Mekong Delta, about 60% of the citrus growers reported the weaver ant *Oecophylla smaragdina* and an equal proportion of sapodilla farmers mentioned the black ant *Dolichoderus thoracicus* as natural enemies. Only about 10% of the mango, durian and longan farmers had any notion of natural enemies. Less than 10% of all the fruit farmers mentioned spiders and only a few farmers noted birds, dragon flies and salamanders.

Both citrus and sapodilla are relatively small trees and these crops have already been cultivated in the Mekong Delta for a long time (Chapter 1). As such these farmers have been better able to acquire knowledge of natural enemies compared to other fruit farmers. Only since the early 1990s, longan has been widely cultivated in the Mekong Delta (Nguyen Bao Ve, pers. comm., 2000) and farmers are highly market oriented, relying solely on chemical pest control (Chapter 1). Except for some longan farmers reporting spiders, they had no idea about natural enemies. Similar to citrus and sapodilla, mango and durian have been cultivated for a long period in the Mekong Delta, but these trees are so tall that perception of both pests and natural enemies is hindered. Mango trees are ideal for the weaver ant *O. smaragdina* to make its nests. However, only two of the 10 mango farmers with *O. smaragdina* in their orchard considered this ant as beneficial. The fact that farmers have to climb their trees to harvest mangoes partly explains why these aggressive ants are less appreciated in this crop.

When farmers avoid or strongly reduce pesticide use, as is the case when farmers practice ant husbandry, the populations of endemic natural enemies, which reduce the populations of potential pests, will be much higher compared to those orchards with high pesticide pressure. So far, no or little scientific information is available for fruit crops in Viètnam about the taxonomy and impact of endemic natural enemies others than ants. Knowing these species and how they interact within the agro-ecosystem offers great potential for improving biological control through habitat manipulation (see section 8.4).

8.2.2. Oecophylla smaragdina

In Figure 8.2.2. an illustration of how weaver ants build their nest is given. Durian leaves are more firm and more difficult to bend than mango leaves, partly explaining why durian trees are less attractive ant nesting sites, as suggested by Way and Khoo (1991). In those few durian orchards where ants occurred, most of which were located in Can Tho Province, the farmers considered *O. smaragdina* to be beneficial. These orchards were all mixed cropping systems with citrus, coconut, rose apple (*Syzygium jambos* (L.) Alston; Myrtaceae) or other non-crop trees serving as ant nesting places. The importance of orchard biodiversity as a major component of conservation biological control will be discussed in a later section.

Oecophylla smaragdina has been traditionally used by citrus farmers in the Mekong Delta for pest control and fruit quality improvement (Barzman *et al.*, 1996; Chapters 4 and 5). With abundant *O. smaragdina*, sweet orange farmers experienced lower pest infestations and/or yield losses due to the citrus stinkbug *R. humeralis*, the aphids *Toxoptera* spp., leaf-feeding caterpillars *Papilio* spp. and inflorescence eaters. In Tieu mandarin, the use of agrochemicals was higher than in sweet orange and pest risk assessment was not correlated with ant abundance, except for aphid infestation that was rated lower. A literature review on the diversity of prey captured by *Oecophylla* spp. has been presented by Dejean (1991). *Oecophylla* seemed erratic as egg predator (Way *et al.*, 1989).

Even though ants such as *O. smaragdina* and *D. thoracicus* have often been reported to tend honeydew-producing Homoptera, *Oecophylla* has never been associated with outbreaks of these pests (Way, 1963; Needham *et al.*, 1986; Huang and Yang, 1987; Löhr, 1992). *Oecophylla* does not attack parasitoids of mealybugs and scales, nor their predators such as the larvae of lacewings and ladybeetles (Huang and Yang, 1987; Olkowski and Zhang, 1998). In China, citrus farmers did not perceive damage caused by mealybugs as significant when weaver ants were present. In neither sweet orange nor Tieu mandarin orchards in the Mekong Delta, Vietnam, was mealybug infestation correlated with the presence of abundant ant populations. Needham *et al.* (1986) wrote that despite the diversity of insect pests in citrus, it is remarkable that the use of one ant species as a principal biological control agent in orchards in southern China has proved to be effective over such a long time, implying that interference of *Oecophylla* with other natural enemies will be limited.

Traditional knowledge has been described as an integrated system of knowledge, practice and beliefs (Berkes *et al.*, 1995). Citrus farmers attribute a better fruit quality to the presence of ants, which were said to increase the juiciness and sweetness of the fruit. Experiments conducted by Barzman *et al.* (1996) confirmed that *O. smaragdina* has an influence on the fruit quality, but only on the shine and juiciness, not on the sugar content. Farmers attribute this effect to the 'ant urine', an effect partly comparable to that of chemical fertilizers. Our studies indicated that Tieu mandarin farmers indeed applied less nitrogen and fewer foliar fertilizers when *O. smaragdina* was present. Besides, yield was not affected. These effects on fruit quality improvement were reported by farmers as being crucial to successful marketing of the fruits, especially of mandarins. Given the increased demand in developed countries for biologically produced food, the practice of weaver ant husbandry offers good potential for export of Vietnamese citrus when proper government support is given. Farmers should be made aware that using biological control agents is more 'modern' than using chemicals, and that increased insecticide application does not automatically equate with increased profits (Kenmore *et al.*, 1987). Over the past century, several authors have stated that the influence of *O. smaragdina* on the economics of citrus culture remains to be determined (Needham *et al.*, 1986). In our study, citrus farmers' expenditure on pesticides was reduced by half when *O. smaragdina* was abundant, without affecting either the yield or the farmers' income (Chapter 4). Nevertheless, more research is needed to assess the impact of the weaver ant on citrus pests in order to optimize its performance.

The potential for applying weaver ant husbandry in perennial crops is not restricted to citrus, or to traditional farming systems. *Oecophylla smaragdina* is currently successfully used in commercial cashew plantations in Australia (Peng *et al.*, 1995). Both the quality and quantity of the nuts is better with ants as biological control agents, compared to chemical control (Peng *et al.*, 1999). Cashew offers the extra advantage in that nuts are harvested by picking them from the ground after having dropped from the tree, eliminating the hindrance harvesters may experience from *O. smaragdina.* In Vietnam, cashew is mainly grown in South Central Vietnam and export has increased from 24,700 tons in 1990 to 95,500 tons in 1995 (DAFF, 1996). In the near future, efforts will be undertaken to introduce *O. smaragdina* in these cashew plantations to reduce production costs (Vo Mai, pers. comm., 2000).

Although *O. smaragdina* has not been accepted by plantation workers in most Asian countries because of intolerance to ant bites (Leela, 1961 and Kalshoven, 1981 in Barzman *et al.*, 1996), weaver ant aggression was identified by only one-third of the citrus farmers in the Mekong Delta. To kill the ants, these farmers sprayed their orchard once prior to harvest. For reasons of consumer safety and conservation of natural enemies, alternative ways of reducing hindrance from ants during harvest should be developed. This could be accomplished by evaluating possibilities of temporary moving ant nests outside the orchard prior to harvest. Most ants return to their nest at night and this moment of reduced foraging activity would be the best time for undertaking such actions. Farmers already know about the weaver ants' diurnal behaviour as most of them have collected nests from native vegetation or exchanged nests with neighbours at night. Another possibility would be to lure ants to non-crop trees by providing food such as chicken intestines. Some farmers reported providing ant bridges made from nylon strings, woven banana leaves or bamboo sticks between the crop and non-crop trees around their house. Once most of the ants have moved out of the citrus trees, the artificial ant bridges could be removed to avoid a fast return of the ants to the crop, until the fruit is harvested.

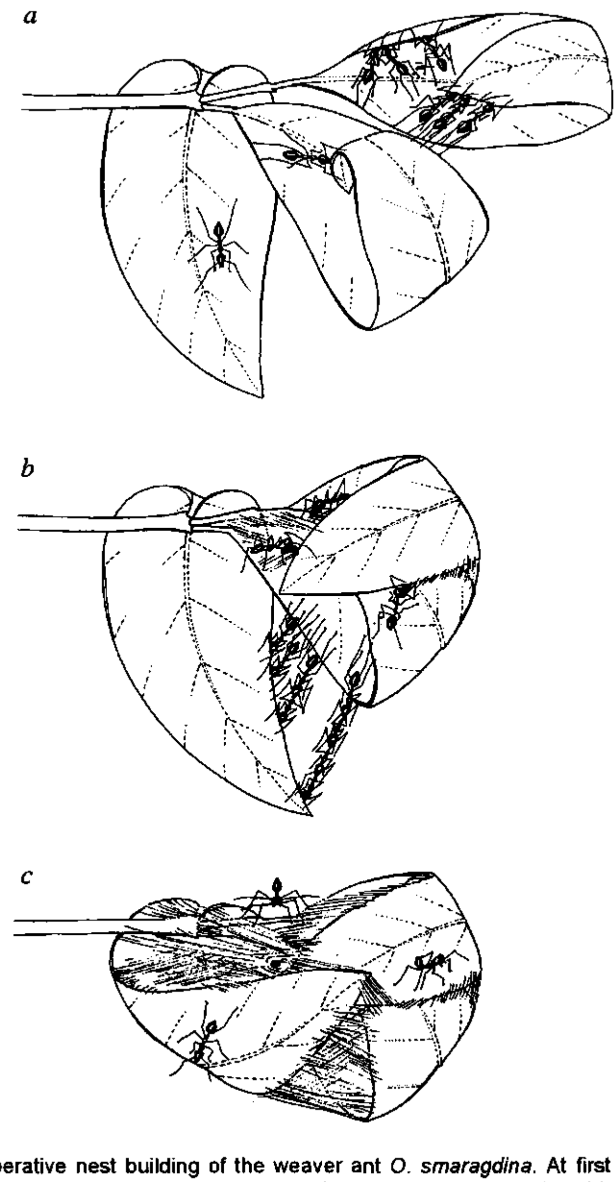

Figure 8.2.2. Co-operative nest building of the weaver ant *O. smaragdina*. At first the workers labour independently in their attempts to pull down or roll up leaves. When success is achieved by one or more of them at any part of the leaf, other workers in the vicinity abandon their own efforts and join in (a). When the leaves have finally been shaped into tentlike configurations, some of the ants continue to hold them in place with their legs and mandibles while others carry partially grown larvae from preexisting nests and bind leaves together with sticky larval silk (b). Sheets of silk are then added to create circular entrances and galleries (c). (Source: Hölldobler and Wilson, 1977).

Except for providing ant bridges to facilitate ants' foraging efficiency between crop trees, weaver ant husbandry also involves colony establishment (Chapter 4). Well-established colonies of *O. smaragdina* can consist of more than one hundred nests that are located in several trees (Hölldobler and Wilson, 1977), and which may comprise up to a million workers and brood (Way and Khoo, 1992). Introducing only a few nests from one colony is not a guarantee for successful colony establishment. Ants often migrate and populations usually drastically decrease within two months after having been introduced. Introduction of partial colonies with a reproductive queen has been reported as more permanent than without a queen (Peng *et al.*, 1998b). Establishment of new colonies indeed often fails because in each colony, the queens apparently remain in one nest only and they are not replaceable (Peng *et al.*, 1998a). According to some farmers, the best period for establishing new colonies is the end of the rainy season (November-December), when many nests contain big larvae which are probably queen larvae. Farmers observed this change in size of the larvae because these are used as fishing bait.

Controlling competing ants is another weaver ant husbandry practice. Citrus farmers never interplant their crop with sapodilla or vice versa, because the black ant *D. thoracicus* competes with *O. smaragdina*. When black ants are present in a citrus orchard, farmers establish artificial nests, such as a ball of dried leaves or grasses, as a trap and burn them after colony establishment.

Whether farmers had a high or low level of education did not influence weaver ant husbandry practice, but farmers practising ant husbandry were generally older. The opening of the market economy in the late 1980s invoked increased fertilizer and pesticide use due to the national agricultural policy and aggressive advertising and marketing techniques of the agro-business (Chapter 1). From 1994 to 1998, insecticide use increased from 66% to 84% in citrus orchards where *O. smaragdina* occurred (Chapter 4). Besides, younger farmers often establish new Tieu mandarin orchards under monocrop without the presence of *O. smaragdina*. Berkes *et al.* (1995) stated that indigenous knowledge is characteristically an attribute of societies with historical continuity in resource use practices. Clearly, if in Vietnam the trend observed over the past ten years persists, this continuity will be lost. Most newcomer Tieu mandarin farmers are highly market oriented (Chapters 1 and 4). They are very sensitive to pesticide promotion and most of them have no knowledge about traditional pest management techniques. Also in the more extensively managed sweet orange, the traditional practice of weaver ant husbandry might be endangered with growing media influence and when extension activities remain confined to chemical pest control (Chapter 6).

8.2.3. Dolichoderus thoracicus

As opposed to the weaver ant, the black ant *D. thoracicus* is not aggressive to man, and so it is not a nuisance to farmers. It constructs its nests in any suitable site whether arboreal or on the ground, such as in palm spadices, leaf axils or leaf litter (Way and Khoo, 1991). *Dolichoderus thoracicus* has been reported to suppress populations of different pests of perennial crops (Khoo and Ho, 1992; Way and Khoo, 1992; CABI, 1998), in particular cocoa, mainly by deterring pests. In the Philippines, both *D. thoracicus* and *O. smaragdina* contributed to the pollination of sapodilla (Coronel, 1994). So far, *D. thoracicus* has not been used as a biological control agent in fruit crops, mainly because the ants also attend mealybugs (Way and Khoo, 1992). In Malaysian orchards it is even considered a pest (Khoo *et al.*, 1993).

In our study, a majority (61%) of the 190 sapodilla farmers interviewed considered *D. thoracicus* as beneficial in decreasing damage by the fruit borer *Alophia* sp. (51%) and the mealybug *Planococcus lilacinus* (43%) (Chapter 3). A significant greater proportion of orchards had *D. thoracicus* in Can Tho than in Tra Vinh Province. The use of high-pressure pumps to spray tree canopies with water has been promoted by the Extension Service of Tra Vinh as a means to combine irrigation with pest control. Because larvae of *Alophia* hatch after three to four days, after which they enter the fruit, the frequency of spraying the trees with high pressure is very important. Even when trees were sprayed every three days, control was far from as good as with ants only (Cuc, unpublished data). Since farmers perceived pest control with high pressure pumps with water only as inadequate, they readily combined it with chemical pest control. This technique most likely reduces the population build-up of *D. thoracicus* decreasing the efficiency of biological control and resulting in a higher pesticide pressure on the environment. The best results of *D. thoracicus* in reducing damage by the fruit borer *Alophia* sp. were obtained in Can Tho, where farmers did not use high pressure pumps, but just bailed water from the canal on the planting beds.

Promoting greater farmers' acceptance of *D. thoracicus* may be difficult, because 30% of all the farmers said that *D. thoracicus* increases mealybug populations. In our on-farm experiments, populations of the mealybug *P. lilacinus* were not enhanced by the ants. Although requiring further investigation, the rather low mealybug populations might be because from time to time farmers poured a sugar solution around the tree bases to attract and feed the ants, as such eliminating the unique dependency of *D. thoracicus* on honeydew-producing Homoptera.

8.3. Pest management

In citrus, some farmers trapped nocturnal fruit-piercing moths by putting a box with pieces of pineapple or banana, drenched in an insecticide in their orchard. The moths were identified as *Ophiusa coronata* (Fabricius) and *Eudocima* spp. (Lepidoptera: Noctuidae) (Cuc *et al.*, 1998). Most mango farmers pruned their trees to reduce further damage by shoot borers, including *Chlumetia transversa* (Walker) (Lepidoptera: Noctuidae) and one other unidentified species. Except for those farmers implementing solely biological pest control with predaceous ants, chemical control was the most common practice for all fruit farmers in the Mekong Delta (Table 8.3.1.).

Table 8.3.1. Pesticide use patterns by fruit farmers, Mekong Delta, 1997-1998.

	Sweet orange *n*=54	Tieu mandarin *n*=78	Longan *n*=171	Mango *n*=93	Durian *n*=36
Insecticide use (%)	83.3	96.2	98.2	96.8	86.1
No. of sprays[1]					
Mean ± SE	3.4 ± 0.3	11.0 ±1.3	11.7 ± 0.9	13.4 ± 0.7	13.2 ± 1.7
Median	2.0	9.0	8.0	12.0	13.0
Maximum	12.0	30.0	48.0	42.0	40.0
Fungicide use (%)	48.1	89.7	71.3	78.5	52.8
No. of sprays[1]					
Mean ± SE	3.8 ± 0.4	10.3 ± 1.3	8.4 ± 0.8	11.6 ± 0.6	5.2 ± 1.0
Median	4.0	8.0	6.0	12.0	4.0
Maximum	7.0	30.0	34.0	21.0	16.0
Herbicide use (%)	22.2	30.8	33.9	31.2	13.9

[1] Based on those farmers using pesticides. At high spray frequencies, insecticides were mostly mixed with fungicides.

The role of women in fruit production is generally restricted to weeding, irrigating the trees and harvesting the fruit. They are never involved in spraying pesticides, which is done by the farmer himself or by hired labour (Chapter 1). In rice production in the Mekong Delta, about 20% of the women were involved in spraying pesticides (Chi *et al.*, 1995). Spraying in orchards is done overhead and farmers sometimes climb their trees when these are too high.

Most farmers relied on their own experience or on information provided through the media for pesticide advice. The relative importance of each pesticide information source depends on the crop grown among other factors (Table 8.3.2.). Direct farmer-to-farmer information flows are generally limited, and happen more in highly commercial crops like longan, mango and Tieu mandarin (Chapter 6) with substantial chemical inputs, than in sweet orange. However, more essential are the indirect information flows from farmer to pesticide seller to farmer. With about one-third of the farmers relying on pesticide sellers for advice, pesticide shop owners are a focal point in pesticide information circulation.

Table 8.3.2. Percentage of farmers reporting pesticide advice sources[1], Mekong Delta, 1997-1998. The relative importance is given in percentages between brackets.

	Sweet orange *n*=54	Tieu mandarin *n*=78	Longan *n*=171	Mango *n*=93	Durian *n*=36
Himself	61.1 (39.8)	59.0 (38.0)	69.6 (36.4)	71.0 (35.9)	72.2 (38.8)
Media	44.4 (28.9)	41.0 (26.4)	47.4 (24.8)	44.1 (22.3)	50.0 (26.9)
Pesticide seller	29.6 (19.3)	15.4 (9.9)	37.4 (19.6)	44.1 (22.3)	41.7 (22.4)
Extension	11.1 (7.2)	21.8 (14.1)	15.8 (8.3)	18.3 (9.2)	11.1 (6.0)
Neighbour	1.9 (1.2)	12.8 (8.3)	21.1 (11.0)	18.3 (9.2)	11.1 (6.0)
University staff	5.6 (3.6)	5.1 (3.3)	0.0 (0.0)	2.2 (1.1)	0.0 (0.0)

[1] Multiple answers occurred.

From the 180 pesticide sellers interviewed, more than 50% of them had other sources of income: five of them were teacher at a local school; 74 of them cultivated rice, vegetables or fruit crops; and 18 sold other products in their shop. Farmers and pesticide sellers exchange information both about pests and products. Only some pesticide sellers had learned about pests through self-study from books or from their own observations in the field (Table 8.3.3.). The majority of the pesticide sellers were notified by the farmers about their major pest problems and about the performance of products applied. All pesticide sellers had obtained general information about pesticides and pesticide use through a training course organized by the PPD. Since 1993 this has been obligatory by the Decree No. 92CP in order to get a license to sell chemicals (Chapter 1). Seemingly, the information provided about pests and pesticides by farmers was more important than that obtained during these courses.

The types of pesticides sold in the shop were primarily based on farmers' demand (87%) and secondly on company promotion (56%). About 70% of all the farmers interviewed mentioned the knock-down effect of insecticides as the major criterion for purchasing a product. The same attitude has been observed for rice farmers in the Mekong Delta, irrespective of having followed an IPM training course in a farmer field school (Chung and Dung, 1996). A preference for products with a fast knock-down effect combined with the readily provision of these products by pesticide sellers has seemingly resulted in farmers using more of the banned insecticides such as methyl parathion and carbofuran when relying on pesticide sellers for advice (Chapter 6). Because recently pesticide sellers need an official certificate to sell pesticides, none of them reported advicing or selling these products.

Table 8.3.3. Percentage of pesticide sellers reporting their information sources for learning about pests and pesticides[1], Mekong Delta, 1998-1999 (*n*=180).

	Where did pesticide seller learn about		
	pests	farmers' pest problems	products
Farmer	8.3	68.9	86.7
Company	0.0	4.4	61.7
Media	0.0	11.1	50.6
Leaflets	0.0	0.0	20.0
Plant Protection Service	6.7	11.7	15.6
Extension Service	0.0	0.0	10.6
Cantho University	0.0	0.0	9.4
Books	19.4	0.0	0.0
Own experience	10.6	0.0	2.8

[1] Multiple answers occurred.

For matters of biocontrol or for using pesticides farmers most relied on their own experience. The technical knowledge embodied in farmer experimentation has been recognized as a valuable resource, often untapped by technology development and transfer institutions (Richards, 1989; Ashby, 1990). The importance of farmers' knowledge about using ants as biological control agents in fruit crops in the Mekong Delta has been described throughout this thesis. Over the past 10 years chemical pest control has become increasingly important. In the tropics farmers experiment with pesticides and not only for controlling pests (Schwab, 1995). In our study, one farmer reported pouring insecticides directly in the canals between the planting beds of his orchard to catch fish. It is well possible that this fact does not stand alone. Because of the physical conditions of the Mekong Delta, water is an extremely important resource used in daily life by millions of people. For reasons of human health and the economic damage to aquatic production, which acounts for more than 10% of the total national export value (DAFF, 1996), strong government intervention related to the import, production and sales of pesticides is called for. The importance of pesticide regulation and implementation in protecting both the farmers and the public health will be discussed in a later section.

Only 2% of the farmers purchased a pesticide based on the safety or price of the product. Most broad-spectrum pesticides in Vietnam are indeed very cheap (Chapter 6). Oudejans (1999) stated that the strong growth in market share of generic pesticides is a disquitening development for IPM implementation in SE Asia. Studies from Indonesia, Malysia, Thailand and Sri Lanka revealed that annually nearly 15% of the pesticide users are poisoned, mainly by organophosphates (Jäger, 1995). Similar data are not available for Vietnam, although local newspapers have recently started to report on pesticide poisonings. Fruit farmers in the Mekong Delta would probably only be concerned about safety if it would affect their own health. Farmers generally lack the knowledge of the effect of pesticides on natural enemies others than ants.

Generally, farmers have a tendency to see every insect as a pest, stimulated in their belief by pesticide advertisements that pesticides offer the only solution of protecting their crop (Bentley, 1992; Schwab, 1995). As a consequence farmers are highly risk averse (Heong *et al.*, 1994; Heong and Escalada, 1997). Rabb *et al.* (1972) stressed that risk considerations vary between farmers, and that these will be more evident for producers who have limited off-farm employment opportunities and little crop diversity among other factors. Generally, sweet orange farmers also cultivate rice and they maintain some crop diversity in their orchard, as opposed to Tieu mandarin farmers (Chapter 4). Risk aversion is therefore much higher in the commercial crops such as Tieu mandarin, mango and longan, accounting for the higher pesticide pressure in these crops.

Farmers in rice (Heong *et al.*, 1994; Heong and Escalada, 1997) and fruit farmers in the Mekong Delta use pesticides primarily for prevention or after observing damage symptoms. Especially in high value crops like Tieu mandarin, mango and durian, pests attacking the fruit are sprayed preventive, because farmers know from experience that these pests can ruin their crop. Mango farmers mainly calendar sprayed during the flowering and fruiting stage, some of them even at 3-4 days intervals, mainly to protect the fruit from seed borer infestation (Chapter 2). Monitoring was never done and sprays were merely prophylactic. Tieu mandarin farmers sprayed throughout the fruiting season to protect their fruit from potential mite damage (Chapters 6 and 7). Pests receiving high pesticide spray loads should be put high on the agenda for future research on alternative control methods.

Leaf-damaging pests such as the citrus leafminer *Phyllocnistis citrella*, on the other hand, were mainly treated after observing the symptoms. All citrus farmers targeted this pest mainly during the dry season when most of the leaves matured and symptoms were clear (Chapter 7). Except for the leafminer population peak in the dry season, following the flower induction treatment, two other peaks occur in the rainy season (Huynh Tri Duc, unpublished data), but remain unnoticed by farmers. Leafminers are protected by the leaf cuticle and are therefore poor targets for contact insecticides. Parasitoids which must forage rapidly over leaf surfaces to find the citrus leafminer are higher vulnerable to pesticides (Waage, 1989). Sprays are targeted at the wrong time, and broad-spectrum insecticides are highly disruptive to beneficials. Therefore, all farmers face problems with the citrus leafminer.

Pesticide use not only influences pest population dynamics, but also that of natural enemies. Some of the fruit farmers in the Mekong Delta did not use any pesticides at all, relying entirely on predatory ants. In orchards with *O. smaragdina*, farmers sprayed less frequently and used fewer insecticides that are highly hazardous (Chapter 4). In sapodilla orchards where *D. thoracicus* were present, 25% fewer farmers sprayed insecticides than farmers without this ant, and those using pesticides sprayed less frequently (Chapter 3).

There are essentially three different approaches for integrating natural enemies with pesticides in pest management programmes: use of selective pesticides or rates, and the temporal and spatial separation of pesticide and natural enemies (Pedigo, 1996; Ruberson *et al.*, 1998).

Although recently the array of selective pesticides available on the market in the Mekong Delta is increasing, most insecticides used in fruit crops are broad-spectrum products which are highly to moderately toxic to humans (WHO toxicity classes I and II) (Chapters 2, 3 and 4). So far, no studies have been conducted related to the toxicity of pesticides to predatory ants. Besides ants, conservation of predatory mites and natural enemies of the citrus leafminer, citrus aphids, scales and mealybugs will be equally important. Since toxicity depends on the species of natural enemies studied, and no extensive information on natural enemies in fruit crops in the Mekong Delta is available (see previous section), appendix 1 may already give some indications on toxicity of those pesticides used and promoted in fruit in Vietnam. Based on international research results (Jäger, 1995; Biobest, 1998; Anonymous, 1999), special attention is paid to human health aspects, toxicity to fish and pollination bees. Reference species of natural enemies have been included based on the occurrence or application of the same species or genus in citrus cropping systems in Asia (CABI, 1998) and/or Australia (Smith *et al.*, 1997). *Amblyseius* spp. and *Phytoseiulus persimilis* Athias Henriot (Acarina: Phytoseiidae) were taken as a reference for predatory mites, and the lacewing *Chrysopa carnea* Stephens (Neuroptera: Chrysopidae) and ladybeetles (Coleoptera: Coccinellidae) were selected as predators of aphids, scales and mealybugs. Besides, the following hymenopterous parasitoids were selected: *Aphidius* spp. (Braconidae) against aphids, *Encarsia formosa* Gahan (Aphelinidae) against whiteflies (Homoptera: Aleyrodidae), and *Trichogramma* spp. (Trichogrammatidae), mainly against lepidopteran pests. Other *Encarsia* spp. are also important parasitoids of scales (Smith *et al.*, 1997). For the product toxicity to predatory mites and parasitoids, the most susceptible species of those previously mentioned species has been included. Those products which are toxic to all these groups of natural enemies are with some probability also likely to be toxic to ants.

Worldwide, resistance of spider mites against organophosphates (OPs) has been reported since the 1950s and later on also against carbamates (Helle and van de Vrie, 1974, Ho, 1984). Up to now, many farmers in the Mekong Delta still apply a lot of OPs which are detrimental for all kinds of natural enemies, pollinators, fish and human beings (Chapters 2, 3 and 4). Smith *et al.* (1997) have stressed that selective acaricides should not be used to control the citrus red mite, because these products are costly and overuse will lead to resistance. Besides, several fungicides such as benomyl and mancozeb reduced populations of the predatory mite *Amblyseius victoriensis* Womersley by 100% (Smith and Papacek, 1991). Copper oxychloride, which fulfils the same disease-control function, was non-toxic to *A. victoriensis*. Although appendix 1 may give some indications, the effect of different insecticides and fungicides should be tested on the prevailing natural enemies present in fruit crops in the Mekong Delta, Vietnam.

Availability of IPM-compatible alternatives for farmers are very important. In several countries, petroleum spray oils (PSO) are currently used in citrus IPM programmes against different pests, including the citrus leafminer, whiteflies, mites, scales and mealybugs (Smith *et al.*, 1997; Huang and Tan, 1998; Huang *et al.*, 1998). Since 1997, PSO have been tested both in northern and southern Vietnam by the Vietnam Biological Control Research Centre (VNBCRC) and SOFRI in the CSIRO-project 'Integrated Control of Citrus Pests in China and SE Asia', and they have been registered for use only since 1999. Preliminary results indicate that PSO can be well integrated with the use of *O. smaragdina* (Huynh Tri Duc, pers. comm., 2000).

In cases where farmers use pesticides, conservation of ants could be improved if sprays would be applied in the evening. At this time, most ants have returned to their nest because diurnal activity is greater than the nocturnal activity (Needham *et al.*, 1986; Dejean, 1990). Avoiding spraying trees where ant nests are located is one of the ant conservation techniques being practiced by most citrus farmers in the Mekong Delta tending *O. smaragdina*. Even better would be also to avoid spraying trees where ants patrol, as is being practiced in the coconut IPM programme to control the bug *Pseudotheraptus wayi* Brown (Heteroptera: Coreidae) with *O. longinoda* Latr. (Julia and Mariau, 1978).

Insecticide use disrupts not only ant populations and their prey. Insecticides are often administered over the entire crop cycle, evoking whole-community disruptions and favouring herbivore species with high reproductive, survival and recruitment rates and with short life spans (Heong and Schoenly, 1998), such as mites and aphids.

8.4. Habitat manipulation

One approach in biological control is the conservation of natural enemies by applying selective pesticides or by the selective use of pesticides. Another approach of conservation biological control is to provide food and shelter for natural enemies. This can be achieved through habitat management. It manages the relationships between pest arthropods, natural enemies, crop and non-crop plants, and their physical environment (Bugg and Picket, 1998). Vegetational diversity can be considered both at the landscape and farm level, with a distinction being made in non-crop plants between the weedy vegetation on the one hand, and non-crop trees on the other hand.

Knowing the natural enemies and their host range is important to determine which natural enemies would be best conserved (Greathead, 1985; Waage, 1989). The conservation of a few natural enemies rather than the conservation of all or most natural enemies in an agro-ecosystem would make the development and acceptance of conservation biological control tactics by farmers easier and more cost-effective (Waage, 1989; Barbosa, 1998). Therefore, identifying the major natural enemies in fruit crops in Vietnam is a first requisite.

Conservation biology not only stresses the conservation of specific natural enemies, but also that of specific plant species. Any manipulation of diversity should be assessed seperately for the pest in terms of alternate host and its natural enemies (Rabb *et al.*, 1972; van Emden and Williams, 1972). The availability of flowers outside the crop has longtime been recognized as important in the adult nutrition of most beneficial insects (van Emden and Williams, 1972; Altieri and Whitcomb, 1979; Andow, 1991; Bugg and Picket, 1998). For example, in Australia, Rhodes grass in the inter-rows produces windblown pollen all year round, increasing the population of the predatory mite *Amblyseius victoriensis* (Smith and Papacek, 1991). However, one of the drawbacks with grass-only understorey is a lack of nectar causing reduced adult longevity of parasitoids like *Trichogramma* spp., widely used for inundative control of lepidopteran pests (Gurr and Wratten, 1999).

Despite the fact that grasses predominate the orchard weed flora in the Mekong Delta (Chapter 7), it would be unwise to promote a ground cover of grasses because rice, the major crop in the Mekong Delta, also belongs to the Poaceae. Grasses not only easily infest rice fields and become noxious weeds, but also assure the carry over of many rice pests between different rice cropping seasons. In the agricultural mosaic of the Mekong Delta, it would be better to establish a ground cover with plants belonging to a different taxonomic family. Asteraceous weeds, for instance, have a short juvenile period and can produce pollen and nectar throughout the year. In China, integrated pest management of citrus arthropod pests is based on protection and utilization of predatory mites (Liang and Huang, 1994). The asteraceous 'weed' *Ageratum conyzoides* L. is planted or conserved as a ground cover in 135,000 ha of citrus orchards to supply pollen for the predatory mites *Amblyseius* spp. These mites and other natural enemies available on ground cover plants are an important source for recolonization of the citrus trees in case these have been sprayed. Altieri (1994) reported that a natural weed complex in citrus enhanced regulation of mites and hard scales (Diaspididae). Selecting beneficial weed species is one thing, maintaining this ground cover at critical periods of the year, yet another. However, before implementing ground cover manipulation, the overall ecological impact on natural enemies, as well as on pests and diseases will have to be assessed. Carefull selection of herbaceous plants is indeed required, because some plants may increase pest and disease problems (Bugg and Waddington, 1994).

Orchard management practices have a significant influence on the availability of pollen and nectar for beneficials (Chapter 7). A common practice of fruit farmers in the Mekong Delta is to remove the sediments of canals after fruits have been harvested. The alluvial sediments are spread over the planting beds, completely covering the weed flora. By doing so, the level of the planting beds are maintained over the years and the canals are kept clean for irrigation or fish culture. Because farmers clean their canals in the dry season, prior to a new growth flush and flowering of the citrus trees, it is very well possible that predatory mites among other beneficials, are suppressed because of food deprivation. Some minor changes could make the practice of canal clearing a more compatible practice within a conservation strategy of biological control in an IPM programme. Besides, small modifications of farmer practices have a better chance of being adopted by farmers (Matteson *et al.*, 1984; Altieri, 1993). One alternative might be that farmers apply the sediments only around the tree base, leaving the rest of the weeds untouched, which is a similar approach as ring weeding. Another alternative would be that farmers clear their canals annually and apply the sediments on alternate planting beds every other year. In this way, the level of the beds is maintained over the years, and weeds remain available to natural enemies during the whole year. Always a part of the ground vegetation should be conserved. During hand weeding, cut weeds can serve as mulch, as is already being practiced now, but should preferably be put around the tree base only. Ideally, weeds could be composted first. Weedy undergrowth is not only important for predatory mites and parasitoids, but also for *O. smaragdina* as Dejean (1991) demonstrated that ants readily foraged the ground for prey after the mangoes had been harvested and prey in the trees were scarce. For optimizing biological control through orchard ground cover management the major natural enemies need to be identified and evaluated, their food and refuge requirements identified, and assessed how these requirements can be best provided by slightly modifying the agro-ecosystem.

Letourneau (1998) illustrated that conservation biological control can learn lessons from conservation biology, for instance from the metapopulation paradigm. Untreated (parts of) fields or natural areas can act as a source of dispersing natural enemies that may rescue local populations from ecological extinction. This is especially important in cases where (1) broad-spectrum insecticide sprays cause local extinction of natural enemies; (2) insecticide treatments are applied differentially across the agricultural mosaic; and (3) natural enemies migrate from one patch to another within the mosaic. This has important implications for land use planning in the conservation of *O. smaragdina* in the Mekong Delta. Because *Oecophylla* is an arboreal species, the distribution of nests of this ant is entirely refined to orchards and residual, natural woody vegetation. However, over the past decades, the natural vegetation in the Mekong Delta has drastically decreased due to increased land pressure (Chapters 1 and 4), reducing the landscape vegetational diversity. In Lai Vung District, Dong Thap Province, Tieu mandarin was nearly the only fruit crop cultivated in 1998 and high pesticide pressure was very common. In Can Tho Province, on the other hand, more different types of orchards, each with a different pesticide pressure, were grown within the agricultural mosaic. Before the 1990s, weaver ants frequently made nests in mango trees, which, given their tall size, offer good refuge. These days, however, spray frequencies in commercial mango orchards are too high too sustain ant populations. Ant nests are only observed in some mango trees serving as intercrop or border plants in citrus orchards, or in those trees grown for own consumption in home gardens.

Indigenous knowledge has valuable information to make production systems more diverse and resilient (Berkes *et al.*, 1995). Some of the traditional resource management principles are (1) maintain a system of refugia to minimize the risk of extinction of any of the biological populations; (2) keep a diversity of crops for food and other commodities; (3) link different production systems to recycle natural resources; and (4) manage the landscape to enhance human well-being. To give but one example of recycling of natural resources in the Mekong Delta, about 15% of the nearly 500 orchards covered in our survey were integrated farming systems with fish cultivation in the canals, and about 50 farmers used fermented fish waste as a foliar fertilizer.

As proposed by Root (1973) in the natural enemies hypothesis, populations of generalist predators may be able to persits in larger numbers and for longer periods in diverse plant communities, because these provide a greater availability of food sources such as prey, nectar and pollen, and shelter. Generalizing the effect of vegetational diversity on ant abundance and predation efficiency is impossible (Perfecto and Castiñeiras, 1998). More important than diversity *per se* in enhancing biological control is the specific condition that is achieved by diversifying the system. Non-crop trees not only provide refuge for natural enemies at times when farmers spray agro-chemicals. They also provide more nesting sites and a more stable food supply from honeydew-producing Homoptera for both the ants *D. thoracicus* and *O. smaragdina* (Dejean, 1990; Way and Khoo, 1991). Sapodilla farmers in the Mekong Delta suggested that the availability of banana plants as an intercrop during the first years of orchard establishment, or as border plants during later stages, increased nesting habits for *D. thoracicus* (Chapter 3). Because of its leaf structure banana plants do not provide nesting sites for *Oecophylla*. This shows that the type of plants used are important in giving *D. thoracicus* a competitive advantage over other dominant ant species like *O. smaragdina*. Close proximity of non-crop vegetation was a major factor influencing the distribution of *O. smaragdina* and their preying efficiency in cashew orchards in northern Australia (Peng *et al.*, 1997; Peng *et al.*, 1998). In Tieu mandarin orchards in the Mekong Delta, both the high pesticide pressure and a less diverse habitat lacking non-crop trees for refuge, have made conditions for *O. smaragdina* particularly difficult compared to sweet orange orchards (Chapter 4).

Concerning improvement of weaver ant husbandry, some potentially important multi-purpose trees can be advocated as border plants or can be mixed within the citrus crop. This has been suggested by Van Mele (1999) based on in-depth discussions with farmers after becoming familiar with the agricultural landscape of the Mekong Delta. *Oecophylla smaragdina* nests are often located in small trees such as *Annona glabra* L. (Annonaceae), which grow along the canals between the planting beds. Farmers typically plant these trees to avoid soil erosion of the canal banks. Nests can also frequently be found in taller trees such as *Spondias dulcis* Soland. Ex Park. and *Mangifera indica* L. (Anacardiaceae), which traditionally provide fruits and shade as an intercrop in many citrus orchards. Another tree preferred by weaver ants is *Ceiba pentandra* (L.) Gaertn. (Bombacaceae), which is also a classical multi-purpose tree. If the trees are not lopped, kapok will be the main product harvested. The light, though strong wood is used in the construction of bridges, which are numerous due to the many small canals in the Mekong Delta. When used as a fence, however, the trees are regularly lopped. The leaves are sun-dried, ground in a small processing unit and subsequently mixed with some olfactory substances. This mixture is directly used for processing incense sticks, which are burnt during religious ceremonies.

Besides available scientific and farmers' knowledge, also the agricultural policy has to be considered when aiming at effective planning of conservation biology. Policy recommendations that encourage agricultural diversification and provide incentives for multiple land-use options are compatible with increasing interests in sustainability (Letourneau, 1998). The Vietnamese government has stipulated to promote agricultural diversification since the *Doi moi* policy reform in the late 1980s (Chapter 1). However, what has actually been promoted is diversification of the agricultural policy, not the agricultural system or mosaic in itself. Increased monetary support has been given to strengthen extension, research and technical services in the fields of fruit production, rather than focusing only on rice production. However, land conversion from paddy fields to orchards has not been stimulated. Intensification of orchards has received support in the form of tax reduction during the first years of orchard conversion from polyculture to oligo- or monoculture. Besides, the planting of a limited number of selected fruit varieties has been promoted. These combined measures have led to a decreased diversity, both in the agricultural landscape and genetic pool. Combined with growing pesticide promotion over the past ten years, the use of endemic natural enemies such as predatory ants is facing increased difficulties. Conservation of natural enemies is strongly hampered and worth very little when economic incentives and agricultural policies reward simplified, chemically based management practices (Levins and Vandermeer, 1990; Waibel, 1993; Ratanawaraha, 1999).

8.5. Conclusions

Despite the fact that there was very little information available on fruit production in Vietnam, and that the author was often restricted to meet farmers, interesting aspects of farmers' KPP, their dynamics and contextual information have been elucidated throughout this thesis.

Contrary to more traditional knowledge-based systems like expert systems used for supporting decision-making, the aim of this study was not to produce definitive and testable recommendations. The KPP approach gives clear indications of where and why farmers' are constrained in acquiring knowledge in certain domains of fruit pest management, and as such helps to set research and extension priorities.

8.6. Recommendations

8.6.1. Further development of a knowledge-based system

To gain deeper insights in what farmers know about the behaviour of their agro-ecosystem, and to make better use of qualitative information, the currently available knowledge base should be further extended based on topics presented in this thesis. These include:

- pesticide applications / weed management - mites - crop yield interactions;
- pesticide applications / weed management - citrus leafminer - crop yield interactions;
- pesticide applications / weed management - predatory ant - crop yield interactions;
- predatory ant - honeydew-producing Homoptera - crop quality interactions;
- predatory ant - non-crop trees - alternative food interactions;
- extension messages - greening disease - pest management interactions.

Methods of knowledge acquisition should be further refined and could be based on those used by Sinclair and Walker (1999), who have recently developed a utilitarian approach to incorporate local knowledge in agroforestry research and extension. Their approach is based on the application of a formal grammar that restricts the syntax of the representation – the process of recording the knowledge articulated by informants -, as well as on the use of a diagrammatic representation of statements combined with linkages between these statements.

The development of a formal knowledge-based system, whether applied to farmers, extension staff or scientists, offers the possibility to measure knowledge increments and as such is an important tool for evaluating research and training impacts.

8.6.2. Farmer training

Widespread gaps in farmers' knowledge, as well as farmers' perception of high input use and promotion of pesticides can influence decisions to practice rational pest management.

More sustainable ways of training farmers to become better decision-makers have been described by many authors and should be promoted in fruit production. Among extension and communication approaches used in crop protection, strategic extension campaigns (Escalada and Heong, 1993; Heong *et al.*, 1998), farmer field schools (Kenmore *et al.*, 1987; van de Fliert, 1993; Ooi, 1996; Vos, 1998) and farmer participatory research (Fujisaka, 1992; Röling and van de Fliert, 1994; Dreves, 1996; Heong and Escalada, 1998) stand out in their ability to bring about significant changes in farmers' pest management practices. Considering the fact that in fruit production in the Mekong Delta pesticide misuse often occurs, changes in pest management practices are urgently required. To facilitate this process, a good understanding of farmers' knowledge, perceptions and practices (KPP) in pest management is needed.

The influence of different information sources on farmers' KPP in pest management has been described to some extent in the previous sections. In the process of information exchange both the contents and dissemination methods of the provided information are important, as well as the socio-economical environment influencing the farmers' attitude towards being receptive to these messages. Some of the constraints in promoting IPM in developing countries have been described as 'farmer individualism' and linking of 'progressive farmer' status with expenses on chemical inputs (Sharma, 1998). Both constraints are prevalent in the Mekong Delta, and might even be more pronounced for farmers growing cash crops such as fruit compared to those cultivating rice.

Farmer individualism and competition is quite strong, not only for fruit farmers with highly commercial orchards, but seemingly also for farmers practicing biological control with *O. smaragdina*. For instance, one citrus farmer was reported to control all major insect pests and diseases, including the citrus greening disease, only by applying weaver ant husbandry and organic farming practices, but he was unwilling to share his knowledge with other farmers or scientists (van den Oever, pers. comm., 2000). Methods should be developed to positively use farmers' attitude towards competition in the development of IPM, rather than to look at it as a constraint. By the end of 1999, one Tieu mandarin farmer received an award from a local government for producing the best quality fruit without using pesticides and by practicing weaver ant husbandry. This event was broadcasted on TV. Local initiatives like this should be further stimulated. Even better would be to organize contests between groups of farmers, for instance between different villages or districts, rather than focusing on the performance of one individual farmer. An 'IPM village of the year award' was identified by Waibel *et al.* (1999) as one of the tools improving extension-community interactions. Because farmers practicing weaver ant husbandry have no forum or platform to exchange ideas among each other, the establishment of 'weaver ant clubs' should receive high priority. Developing platforms for farmer decision-making has been described as an interesting area of extension research (Röling and van de Fliert, 1994). An example of how durian farmers in the Mekong Delta were initially reluctant to share information, but then enrolled in farmer-to-farmer information exchange has been described in box 1.3.3. This, however, was a one-time happening. In the Mekong Delta, the spin-off effects of farmer-to-farmer information exchange in rice IPM have been negligeable without continuous and appropriate technical and institutional support (Dang, 1997).

The second constraint, namely the social interpretation attributed to a 'progressive farmer' is more prominent for farmers cultivating high value cash crops such as Tieu mandarin, mango, durian and longan than for farmers cultivating sweet orange or sapodilla. In Can Tho, an Horticultural Association was established in 1992 by the Faculty of Agriculture, Cantho University, initially to have a stronger bargaining position for lending money from the bank (Chapter 1). During meetings organized by these 'advanced farmer clubs' chemical pest control and use of inorganic fertilizers is high on the agenda. Chemical products from the An Giang Pesticide Company are for sale and farmers can ask advice directly from the university staff. As some academic staff are involved in pesticide promotion activities during these meetings and during the very popular, annual Agricultural Fair in Can Tho, the idea that chemical pest control is modern or advanced, is further strengthened.

Because in the Mekong Delta nearly all the staff from the chemical companies, the Extension Service (ES) and the Plant Protection Sub-Department (PPSD) are graduate students from the Cantho University, there exists a strong 'friendship lineage' between the academic world, extension and the agro-business. Very often these different stakeholders are involved in extension activities, during which mostly 'advanced farmers' are invited. When analyzing the results from the nearly 500 farmers involved in our survey, those getting pesticide advice through extension activities were significantly younger and had a higher educational level ($P<0.05$). Obviously younger farmers are fitter for climbing the trees when these need to be sprayed, they still have a long life ahead, and they have less experience in other pest management practices, which all together makes them commercially more attractive to invest in.

Media advertisements, extension activities and pesticide sellers' recommendations all influence farmers' pest management practices leading to increased use of agrochemicals (Chapters 2 and 6). Because most natural enemies are killed by the broad-spectrum pesticides, new pest problems are created as such reducing the potential usefulness of the ant *O. smaragdina* as a biological control agent. So far, biological control in general, and weaver ant husbandry in particular, has been neglected in most extension activities. Training of young farmers, plant protection and extension staff by both scientists and more experienced, older farmers who practice weaver ant husbandry, could offer good possibilities in a society where Confucianism is part of daily life. In Confucianism, both teachers and elders are highly respected.

Training farmers about the role of natural enemies other than the larger, easy-to-observe predators, will be an even bigger challenge for the future. According to Matteson *et al.* (1984), a pragmatic attitude is typical for the cultural background of SE Asia, where rural people prefer immediate and concrete actions at the cost of abstractions and preventive measures. The relatively long period before effects of *Bacillus thuringiensis* (Bt) against larvae of the diamondback moth *Plutella xylostella* Linnaeus (Lepidoptera: Yponomeutidae) becomes clear, has limited its general acceptance by vegetable farmers in Vietnam (Nguyen Huu Phuc, pers. comm., 1998). For similar reasons, explaining to farmers about the concept and benefits of parasitoids might be difficult. The concept of predation, on the other hand, is well known by most farmers. Weaver ant predation could be used as a starting point for farmers to learn about the existence and role of predatory mites and ladybeetles. Building on what farmers know through enhancing observation with microscopes or hand lenses has previously proven useful (Bentley, 1992; Bentley *et al.*, 1994; Ooi, 1996). The government has a very important role to play in promoting both the further development and dissemination of biological control practices in order to attain a more sustainable agricultural system.

So far, mainly the regional production priorities has determined the frequency and content of extension activities in fruit production. Citrus farmers in Dong Thap have attended more extension courses than those in Can Tho Province. The ES of Can Tho Province has given more emphasis to rice and vegetable cultivation, whereas citrus only received some attention due to increased problems with the citrus greening disease. Besides citrus, no other major fruit crops are grown in this Province. In Dong Thap Province, the situation is different. Lai Vung District has a large area of intensive Tieu mandarin cultivation, with mango and longan also being major crops in other districts of this province. Therefore, the ES in Dong Thap has organized quite some seminars for fruit farmers.

To increase farmers' knowledge about their agro-ecosystem and especially about inconspicuous pests, it is important to make farmers better decision-makers. However, this increased knowledge can also ensue higher pesticide use. Extension in Dong Thap seemingly had a major influence on farmers' knowledge and perception, especially of smaller, difficult-to-observe organisms such as mites and thrips (Chapter 6). However, this increased knowledge resulted in increased use of pesticides such as methidathion, fenpropathrin, sulphur and propargite for targeting these 'newly observed' pests. Because most farmers did not have hand lenses and monitoring was never practiced, sprays were applied from flowering to harvest at regular intervals. Farmer training through extension seminars or mass media, out of the context of their own field, indeed has often led to such situations where farmers were told which pests they had and how to chemically control them (Escalada and Heong, 1993; van de Fliert, 1993). In such cases, the farmer has been denied the necessary knowledge and consequently it is not the farmer but the extension officer, scientist or media who is the decision-maker.

In the Mekong Delta, fruit farmers as rice farmers targeted leaf-damaging pests (Chapters 2, 3, and 5). It would be adviceable to induce farmer experimentation in order to evaluate whether these pests affect the yield, and, in case they do, assess whether sprays are economically justified. Zadoks (1985) stated that damage thresholds are only relatively independent of economic conditions beyond the farm gate if the price of the produce is fixed. The high fluctuations of the price of fruit in the Mekong Delta, due to many factors including annual changes in supply, seasonality and transport to the markets (Chapter 1), makes the concept of damage thresholds less valid and useful. Besides, the concept of thresholds for chemical pest control is increasingly difficult to realize in situations where farmers cultivate a small area and when the agricultural landscape is highly diverse (van Huis and Meerman, 1997). Whenever possible, simple rule-of-thumbs should be developed, as has been done for leaffolder control in rice (Heong and Escalada, 1998; Heong *et al.*, 1998).

8.6.3. Training of government staff

In Vietnam, the PPD and ES have a strong hierarchical structure (Chapter 1). At the provincial level, several engineers, mostly graduates or post-graduates from the Cantho University, work together with a team of technicians, whereas at the district level only three to four technicians are employed per about 20,000 to 40,000 farmers. Expertise in fruit production in general, and in pest management in particular, is often limited to non-existant.

The involvement of the PPD in the national rice IPM programme and more recently, and to a more limited extent, of the ES in the vegetable IPM programme has been described in Chapter 1. The main question is what exactly can be learned from the farmer field school approach being used in rice, vegetables and tea in Vietnam and elsewhere for improving the development of an IPM fruit programme. Matteson (1996) wrote that similar as for scientists, also staff from the PPSD and ES must be willing to relinquish much of their power and status to learn from and together with the farmers. When rice IPM facilitators from the PPSD were asked to organize a farmer field school in tea plantations in northern Vietnam, they lacked the initiative and motivation to start studying the tea agro-ecosystem (den Braber, pers. comm., 2000). Later on, this situation improved because more scientific data became available and a better back-up could be provided to the individual trainers, which improved their power and status. In Tien Giang Province, a similar problem was reported by Nguyen Hoang Dung (pers. comm., 2000). In 1998, the provincial government sponsored a farmer field school for citrus in two villages, which was the first time this happened for fruit in Vietnam. Two rice IPM trainers organized sessions for half a day per week, during 14 weeks. Similarly as in tea, the trainers felt rather uncomfortable because they realized that the farmers knew more about the citrus agro-ecosystem than they did. At the end of the sessions their general appreciation was that the IPM training could have been much better given a better scientific back-up. Both examples illustrate that the dynamic process of reciprocal learning through field studies can indeed be blocked as long as the facilitator feels uncomfortable because of a lack of knowledge. Feeling confident about the technical, scientific background was seemingly a prerequisite for trainers to become facilitators instead of lecturers sticking to a well-defined agenda. In Vietnam, there exists a general lack of information, and especially of information based on local conditions. Therefore Vuong *et al.* (1995) suggested that the PPSD should benefit from farmers' experience in developing technical recommendations, rather than waiting for scientific data to be presented in ready-made advice.

Another challenge will be to devise ways to interest staff from the PPSD and ES in reducing pesticide applications and in promoting the use of *O. smaragdina*. So far, no or little scientific information exists on beneficial organisms in fruit crops in Vietnam. In the future, rearing facilities could be developed to commercialize natural enemies such as phytoseiid mites like *Amblyseius* spp., which could complement predation by *Oecophylla*. Involvement of PPSD and extension officers in production, promotion and distribution of natural enemies might offer good opportunities.

8.6.4. Other government support

The governments' pesticide policy has been described in Chapter 1. In 1994, the use of methyl parathion was banned for use in agriculture, followed by a general ban in 1996. Our studies in mango (Chapter 2), sapodilla (Chapter 3) and citrus (Chapter 4) indicated that still many farmers applied this highly toxic product. Similarly, despite of being banned for use in agriculture in 1998, methamidophos and monocrotophos were still readily applied in rice (Chiem *et al.*, 2000) and vegetables (Hai *et al.*, 2000). Pesticide residues of methamidophos in cucumber and mustard samples collected from the market were 14 and 75 times the maximum residue limit (MRL), respectively. A lack of policy implementation has been identified as one of the major problems for developing IPM in Vietnam (Anonymous, 1997).

Both in developed and developing countries, sufficient examples suggest that it is erroneous to assume that interventions designed to reduce pesticide use will necessarily have a negative impact on farm productivity (Waibel and Engelhardt, 1988; van Lenteren, 1997; Pincus *et al.*, 1999). Rather than looking at yield maximization, optimalization of the farmers' income should be considered. In both sweet orange and Tieu mandarin, about 50% less money was spent on pesticides when *O. smaragdina* was present without affecting the yield (Chapter 4).

The amount of pesticide applied by farmers is governed by their subjective assessment of the risk of crop loss and the information about alternative methods of control (Pincus *et al.*, 1999). Zadoks (1985) differentiated farmers' perception into problem-oriented and option-oriented perception. The first case occurs with the introduction or intensification of a harmful organism. During the first years farmers typically overestimate the risk and overreact to its appearance. The current perception of mite pests by Tieu mandarin farmers in the Mekong Delta could be classified as such, and it could be postulated that the agro-business prefers to keep farmers in this state of mind. Once the problem is well defined and farmers become well informed, perceptions may change to option-oriented. This, off course, implies that a range of options is available, a situation which can only be procured with government support. In Vietnam, research on biological control is very limited. Although the concept of biological control in citrus by *O. smaragdina* is well-known in the Vietnamese society, and appreciated by many farmers, financial support for scientific research has been very limited, and results obtained so far can be merely attributed to a very limited group of enthousiastic researchers. To provide farmers with a basket of options, redirecting research in pest control from chemically-based to biologically-based, sustainable solutions is a must (Way, 1990; Waibel, 1993; van Lenteren, 1997).

Currently, Tieu mandarin farmers do not seem to trust or rely on the traditional practice of weaver ant husbandry anymore. Over the past ten years, the government policy has stimulated crop intensification leading to increased use of agrochemicals (Chapter 1). Especially fruit farmers cultivating monocrops like Tieu mandarin have responded to this tendency. The high pesticide load has created new problems with mites, thrips, scales and mealybugs, which cannot be tackled by *O. smaragdina* without the presence of other natural enemies. As the government has not stimulated research for identifying/promoting biological control agents, increasingly more pesticides are used leading farmers into the so-called pesticide treadmill. Maybe in the near future, problems with pest resistance, pest resurgence and increased environmental pollution will automatically usher more government support for developing IPM in fruit crops. IPM has indeed been most successful, both for procuring government support and farmers' acceptance, in high value crops such as citrus, cotton and soybeans, and where farmers had previously been trapped in the pesticide treadmill (Morse and Buhler, 1997).

One way to increase farmer's net return with reduced pesticide use is to add external costs to the actual costs of pesticides (van Lenteren, 1997). These external costs should compensate for human health problems and environmental hazards. The price paid for a pesticide would therefore be the social, rather than the private cost. Despite of a sophisticated regulatory framework in Germany, measurable external costs amount to at least 25% of the value of pesticides sold in the market (Waibel and Fleischer, in Pincus *et al.*, 1999). When measuring only the health cost of pesticide use in rice in the Mekong Delta, a tax level of about 33% would have to be imposed on current pesticide prices (Dung and Dung, 1999). Ultimately, an economic evaluation of the importance of beneficial organisms in pest management should be included in the pesticide pricing policy (Waibel, 1993), and tests on pesticide effects on indigenous biological control agents, like this is applied in the European Commission (EC) pesticide registration process nowadays (van Lenteren, pers. comm., 2000), should be build into the registration process for chemical pesticides (Williamson, 1998).

Only an integrated approach with equal attention being paid to developing solutions at the farm and policy level has a proper chance of contributing to a more profitable and sustainable agriculture, reduced risks of human intoxications, and a better environment for the Vietnamese people of today and tomorrow.

References

Altieri, M. A. 1993. Designing and improving pest management systems for subsistence farmers. In: M. A. Altieri (ed.) Crop Protection Strategies for Subsistence Farmers. Westview Press, Boulder, Colorado, pp. 1-44.

Altieri, M. A. 1994. Biodiversity and Pest Management in Agroecosystems. The Haworth Press, New York, pp. 185.

Altieri, M. A. and Whitcomb, W. H. 1979. The potential use of weeds in the manipulation of beneficial insects. Hortscience, 14, 12-18.

Andow, D. A. 1991. Vegetational diversity and arthropod population response. Annual Review of Entomology, 36, 561-586.

Anonymous 1997. National IPM meeting. FAO Intercountry Program, Hanoi, 27-28 March 1997. MARD, Hanoi, Vietnam, 27 pp.

Anonymous 1999. Database on pesticides and the environment. Economic and Social Commission for Asia and the Pacific (ESCAP), Centre de co-opération

Internationale en Recherche Agronomique pour le Développement (CIRAD), Commission of the European Union (EU). http://www.fadinap.com/pesticide.

Ashby, J. A. 1990. Small farmers' participation in the design of technologies. In: M. A. Altieri and S. B. Hecht (eds) Agroecology and Small Farm Development. CRC Press, Boca Raton, pp. 245-253.

Aubert, B. 1990. Prospects for citriculture in Southeast Asia by the year 2000. FAO Plant Protection Bulletin, 38, pp. 151-173.

Barbosa, P. 1998. Agroecosystems and conservation biological control. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 39-54.

Barzman, M. S., Mills, N. J. and Cuc, N. T. T. 1996. Traditional knowledge and rationale for weaver ant husbandry in the Mekong Delta of Vietnam. Agriculture and Human Values, 13(4), 2-9.

Bentley, J. W. 1992. The epistemology of plant protection: Honduran campesino knowledge of pests and natural enemies. In: R.W. Gibson and A. Sweetmore (eds) Proceedings of a Seminar on Crop Protection for Resource-Poor Farmers. CTA/NRI, pp. 107-118.

Bentley, J. W. and Andrews, K. L. 1991. Pests, peasants, and publications: anthropological and entomological views of an integrated pest management program for small-scale Honduran farmers. Human Organization, 50, 113-124.

Bentley, J. W., Rodriguez, G. and Gonzalez, A. 1994. Science and people: Honduran campesinos and natural pest control inventions. Agriculture and Human Values, 11, 178-182.

Berkes, F., Folke, C. and Gadgil, M. 1995. Traditional ecological knowledge, biodiversity, resilience and sustainability. In: C. A. Perrings, K. G. Maeler, C. Folke, C. S. Holling and B. O. Jansson (eds) Biodiversity Conservation, Problems and Policies. Kluwer Academic Publishers, Dordrecht, pp. 281-299.

Biobest 1998. Side Effects of Pesticides on Bumblebees and Beneficials. Biobest NV, Westerlo, Belgium, 19 pp.

Bugg, R. L. and Waddington, C. 1994. Using cover crops to manage arthropod pests of orchards: a review. Agriculture, Ecosystems & Environment, 50, 11-28.

CABI 1998. Crop Protection Compendium – CDRom Module 1. CAB International, Wallingford, U.K.

Chi, T. T. N., Khoa, N. T., Tam, B. T. T. and Paris, T. R. 1995. Gender roles in rice farming systems in the Mekong River Delta: an exploratory study. In: G. L. Denning and V. T. Xuan (eds) Vietnam and IRRI: A Partnership in Rice Research. Proceedings of a Conference held in Hanoi, Vietnam, May 4-7, 1994, pp. 291-299.

Chiem, N. H., Tuyen, T. Q., Bac, T. C. and Du, L. V. 2000. Impact of intensive cultivation of triple rice cropping on the agro-ecological environment of the Mekong Delta. Paper presented at the First Joint Workshop on Environmental Conservation and Sustainable Agriculture, Cantho University, January 19-21, 2000. JICA-CTU Project for the improvement of environmental education in agricultural sciences. (in Vietnamese).

Chung, D. K. and Dung, K. T. 1996. Pest Management in Rice Production in Vietnam: a Socioeconomic Assessment. Hanoi Agricultural University, Hanoi, pp. 67.

Coronel, R. E. 1994. Promising Fruits of the Philippines. University of the Philippines, Los Baños, pp. 508.

Cuc, N. T. T., Hung, N. V. and Dien, L. Q. 1998. Insect pests on citrus, durian, longan and mango in selected provinces of the Mekong Delta of Vietnam. In: P. Van Mele and N. V. Huynh (eds) Proceedings of the First Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management. Cantho University, Can Tho, Vietnam, pp. 71-76. (in Vietnamese).

DAFF (Department of Agriculture, Forestry and Fishery) 1996. Statistical Data of Agriculture, Forestry and Fishery 1985-1995. Statistical Publishing House, Hanoi, 411 pp.

Dang, N. P. 1997. Le rôle de la vulgarisation dans la promotion de la culture des arbres fruitiers dans le Delta du Mékong. Mémoire diplôme du Master VOPA. Centre National d'Études Agronomique des Régions Chaudes, Montpellier, pp. 114.

Dejean, A. 1990. Circadian rhytm of *Oecophylla longinoda* in relation to territoriality and predatory behaviour. Physiological Entomology, 15, 393-403.

Dejean, A. 1991. Adaption d' *Oecophylla longinoda* (Formicidae-Formicinae) aux variations spatio-temporelles de la densité de proies. Entomophaga, 36, 29-54.

de Kraker, J. 1996. The potential of natural enemies to suppress rice leaffolder populations. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 257.

Dung, N. H. and Dung, T. T. T. 1999. Economic and health consequences of pesticide use in paddy production in the Mekong Delta, Vietnam. EEPSEA Research Report, Vietnam National University, Ho Chi Minh City.

Ehler, L. E. 1998. Conservation biological control: past, present and future. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 1-8.

Escalada, M. M. and Heong, K.L. 1993. Communication and implementation of change in crop protection. In: D. J. Chadwick and J. Marsh (eds) Crop Protection and Sustainable Agriculture. Wiley, Chisester, pp. 191-207.

Fujisaka, S. 1992. Will farmer participatory research survive in the International Agricultural Research Centres? Gatekeeper Series No. SA44. International Institute for Environment and Development, London, pp. 3-14.

Greathead, D. J. 1985. The importance of taxonomy in biological control: identification and information services: insect orders of major importance. In: P. Ferrar and D.-H. Stechmann (eds) Biological Control in the South Pacific, pp. 105-119.

Gurr, G. M. and Wratten, S. D. 1999. 'Integrated biological control': a proposal for enhancing success in biological control. International Journal of Pest Management, 45, 81-84.

Hai, T. V., Ba, T. T., Son, P. K., Hai, T. T., Nga, N. T. T., Dung, H. A. and Tri, T. V. 2000. Survey of cultivation practices, pesticide use and pest control in vegetables in Can Tho, Soc Trang and An Giang Province in 1998. Paper presented at the First Joint Workshop on Environmental Conservation and Sustainable Agriculture, Cantho University, January 19-21, 2000. JICA-CTU Project for the improvement of environmental education in agricultural sciences. (in Vietnamese).

Heong, K. L. and Escalada, M. M. 1997. Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, Philippines, 245 pp.

Heong, K. L. and Escalada, M. M. 1998. Changing rice farmers' pest management practices through participation in a small-scale experiment. International Journal of Pest Management, 44, 191-197.

Heong, K. L. and Schoenly, K. G. 1998. Impact of insecticides on herbivore-natural enemy communities in tropical rice ecosystems. In: P. T. Haskell and P. McEwen (eds) Ecotoxicology: Pesticides and Beneficial Organisms. Chapman & Hall, London, pp. 381-403.

Heong, K. L., Escalada, M. M. and Mai, V. 1994. An analysis of insecticide use in rice: Case studies in the Philippines and Vietnam. International Journal of Pest Management, 40, 173-178.

Heong, K. L., Escalada, M. M., Huan, H. and Mai, V. 1998. Use of Communication media in changing rice farmers' pest management in the Mekong Delta, Vietnam. Crop Protection, 17, 413-425.

Hölldobler, B. K. and Wilson, E. O. 1977. Weaver ants. Scientific American, 237, 146-154.

Huang, H. T. and Yang, P. 1987. The ancient cultured citrus ant. Bioscience, 37, 665-671.

Huang, M. and Tan, B. 1998. Ecology and management of citrus leafminer in China: a review. In: Proceedings of the International Conference of IPM, Guangzhou, China, p. 134.

Huang, M., Beattie, G. A. C., Watson, D. M., Cen, Y. J., Wang, B. Z., Liang, W. G., Tan, B. and Rae, D. J. 1998. Efficacies of three different petroleum spray oils against a range of pests on citrus in southern China: C21, C23, C27. In: Proceedings of the International Conference of IPM, Guangzhou, China, p. 130.

Jäger, I. 1995. The hazards of pesticide use for man and the ecosystem. In: R. Altenburger (ed.) Pesticides in Tropical Agriculture – Hazards and Alternatives. Margraf Verlag, Weikersheim, pp. 23-61.

Julia, J. F. and Mariau, D. 1978. La punaise du cocotier: *Pseudotheraptus* sp. in Côte d'Ivoire. 1. Études pré-alables à la mise au point d'un méthode de lutte intégrée. Oléagineaux, 33, 65-75.

Kenmore, P. E., Litsinger, J. A., Bandong, J. P., Santiago, A. C. and Salac, M. M. 1987. Philippine rice farmers and insecticides: thirty years of growing dependancy and new options for change. In: J. Tait and B. Napompeth (eds) Management of Pests and Pesticides. Farmers' Perceptions and Practices. Westview Press, Boulder, Colorado, pp. 98-108.

Khoo, K. C. and Ho, C. T. 1992. The influence of *Dolichoderus thoracicus* (Hymenoptera: Formicidae) on losses due to *Helopeltis theivora* (Heteroptera: Miridae), black pod disease, and mamalian pests in cocoa in Malaysia. Bulletin of Entomological Research, 82, 485-491.

Khoo, K. C., Ooi, P. A. C. and Ho, C. T. 1993. Crop Pests and Their Management in Malaysia. Tropical Press Sdn. Bhd., Kuala Lumpur, 242 pp.

Letourneau, D. K. 1998. Conservation biology: lessons for conserving natural enemies. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 9-38.

Levins, R. and Vandermeer, J. H. 1990. The agroecosystem embedded in a complex ecological community. In: C. R. Caroll, J. H. Vandermeer and P. M. Rosset (eds) Agroecology. McGraw-Hill, New York, pp. 341-362.

Liang, W. G. and Huang, M. D. 1994. Influence of citrus orchard ground cover plants on arthropod communities in China: a review. Agriculture, Ecosystems & Environment, 50, 29-37.

Löhr, B. 1992. The pugnacious ant, *Anoplolepis custodiens* (Hymenoptera: Formicidae) and its beneficial effect on coconut production in Tanzania. Bulletin of Entomological Research, 82, 213-218.

Mai, V., Huan, N. H., Heong, K. L., Escalada, M. M. and Lazaro, A. A. 1997. Rice farmers' pest management perceptions and practices in Long An province, Vietnam. In: K. L. Heong and M. M. Escalada (eds) Pest Management of Rice Farmers in Asia. International Rice Research Institute, Manila, pp. 215-226.

Matteson, P. C. 1996. Implementing IPM: policy and institutional revolution. Journal of Agricultural Entomology, 13, 173-183.

Matteson, P. C., Altieri, M. A. and Gagné, W. C. 1984. Modification of small farmer practices for better pest management. Annual Review of Entomology, 29, 383-402.

Morse, S. and Buhler, W. 1997. Integrated pest management: Ideals and Realities in Developing Countries. Lynne Riener Publishers, London, 171 pp.

Needham, J., Gwei-Djen, L. and Hsing-Tsung, L. 1986. The citrus ant story. In: Science and Civilisation in China. Biology and Biological Technology. Part 1: Botany. Cambridge University Press, Cambridge, pp. 531-544.

Norton, G. A. and Mumford, J. D. 1983. Decision making in pest control. Advanced Applied Biology, 8, 87-119.

Ochou, G. O., Matthews, G. A. and Mumford, J. D. 1998. Farmers' knowledge and perception of cotton insect pest problems in Cote d'Ivoire. International Journal of Pest Management, 44, 5-9.

Olkowski, W. and Zhang, A. 1998. Habitat management for biological control, examples from China. In: C. H. Pickett and R. L. Bugg (eds) Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, California, pp. 255-270.

Ooi, P. A. C. 1996. Experience in educating rice farmers to understand biological control. Entomophaga, 41, 375-385.

Othman, Y. and Suranant, S. 1995. The Production of Economic Fruits in South-East Asia. Oxford University Press, New York, 419 pp.

Oudejans, J. H. M. 1999. Studies on IPM policy in SE Asia. Two centuries of plant protection in Indonesia, Malaysia and Thailand. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 316.

Pedigo, L. P. 1996. Entomology and Pest Management. Prentice Hall, Upper Saddle River, New Jersey, pp. 679.

Peng, R. K., Christian, K. and Gibb, K. 1995. The effect of the green ant *Oecophylla smaragdina* (Hymenoptera: Formicidae), on insect pests of cashew trees in Australia. Bulletin of Entomological Research, 85, 279-284.

Peng, R. K., Christian, K. and Gibb, K. 1997. Distribution of the green ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae), in relation to native vegetation and the insect pests in cashew plantations in Australia. International Journal of Pest Management, 44, 203-211.

Peng, R. K., Christian, K. and Gibb, K. 1998a. How many queens are there in mature colonies of the green ant, *Oecophylla smaragdina* (Fabricius)? Australian Journal of Entomology, 37, 249-253.

Peng, R. K., Christian, K. and Gibb, K. 1998b. The effect of non-crop vegetation on the insect pests and their natural enemies in cashew (*Anacardium occidentale* L.) plantations. Plant Protection Quarterly, 13, 16-20.

Peng, R. K., Christian, K. and Gibb, K. 1999. The effect of colony isolation of the predacious ant, *Oecophylla smaragdina* (F.) (Hymenoptera: Formicidae), on protection of cashew plantations from insect pests. International Journal of Pest Management, 45, 189-194.

Perfecto, I. and Castiñeiras, A. 1998. Deployment of the predaceous ants and their conservation in agroecosystems. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 269-289.

Pincus, J., Waibel, H. and Jungbluth, F. 1999. Pesticide policy: an international perspective. In: N. Poapongsakorn, L. Meenakanit, H. Waibel and F. Jungbluth (eds) Approaches to Pesticide Policy Reform – Building Consensus for Future Action. Pesticide Policy Project Publication Series No. 7. Institute for Economics in Horticulture, Hannover, pp. 4-22.

Rabb, R. L., Stinner, R. E. and Carlson, G. A. 1972. Ecological principles as a basis for pest management in the agroecosystem. In: Concepts of Pest Management. Lecture notes, North Carolina State University, Raleigh, pp. 19-44.

Ratanawaraha, C. 1999. Agricultural research for environmental conservation: new dimensions of plant protection. In: Poapongsakorn, N., Meenakanit, L., Waibel, H. and Jungbluth, F. (eds) Approaches to Pesticide Policy Reform – Building Consensus for Future Action. Pesticide Policy Project Publication Series No. 7. Institute for Economics in Horticulture, Hannover, pp. 52-62.

Richards, P. 1989. Farmers also experiment: a neglected intellectual resource in African science. Discovery and Innovation, 1, 19-25.

Röling, N. and van de Fliert, E. 1994. Transforming extension for sustainable agriculture: the case of integrated pest management in rice in Indonesia. Agriculture and Human Values, 11, 96-108.

Root, R. B. 1973. Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). Ecological Monographs, 43, 95-124.

Ruberson, J. R., Nemoto, H. and Hirose, Y. 1998. Pesticides and conservation of natural enemies in pest management. In: P. Barbosa (ed.) Conservation Biological Control. Academic Press, New York, pp. 207-220.

Schwab, A. 1995. Development workers report on their experiences. In: R. Altenburger (ed.) Pesticides in Tropical Agriculture. Margraf Verlag, Weikersheim, Germany, pp. 11-22.

Sharma, M. C. 1998. Integrated pest management in developing countries. RIS Biotechnology and Development Review, 2, 9-18.

Sinclair, F. L. and Walker, D. H. 1999. A utilitarian approach to the incorporation of local knowledge in agroforestry research and extension. In: L. E. Buck, J. P. Lassoie and E. C. M. Fernandes (eds) Agroforestry in Sustainable Agricultural Systems. CRC Press LLC, USA, pp. 245-275.

Smith, D. and Papacek, D. 1991. Studies of the predatory mite *Amblyseius victoriensis* (Acarina: Phytoseiidae) in citrus orchards in south-east Queensland: control of *Tegolophus australis* and *Phyllocoptruta oleivora* (Acarina: Eriophyidae), effect of pesticides, alternative host plants and augmentative release. Experimental & Applied Acarology, 12, 195-217.

Smith, D., Beattie, G. A. C. and Broadly, R. 1997. Citrus pests and their natural enemies. Integrated pest management in Australia. Queensland Dept. of Primary Industries, pp. 272.

van de Fliert, E. 1993. Integrated Pest Management: Farmer Field Schools Generate Sustainable Practices. A Case Study in Central Java Evaluating IPM Training. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 404.

van Emden, H. F. and Williams, G. F. 1974. Insect stability and diversity in agro-ecosystems. Annual Review of Entomology, 19, 455-475.

van Huis, A. and Meerman, F. 1997. Can we make IPM work for resource-poor farmers in sub-Saharan Africa? International Journal of Pest Management, 43, 313-320.

van Lenteren, J. C. 1997. From *Homo economicus* to *Homo ecologicus*: towards environmentally safe pest control. In: D. Rosen, Tel-Or, E., Hadar, Y. and Chen, Y. (eds) Modern Agriculture and the Environment. Kluwer Academic Publishers, Dordrecht, pp. 17-31.

Van Mele, P. 1998. Integrated fruit production of mango and durian in the eastern region of Thailand. Report on a short-term evaluation mission of the 'IPM in selected fruit trees' Thai-German project. Technical report No. 2 of the IPM in fruit project, KU Leuven, Belgium, 22 pp.

Van Mele, P. 1999. Living fences of orchards in Southern Vietnam. Non-Wood News, 6, 48-49.

van Schoubroeck, F. 1999. Learning to fight a fly: developing citrus IPM in Bhutan. Wageningen Agricultural University, the Netherlands, Doctoral dissertation, pp. 200.

Vos, J. 1998. Development of decision-making tools for vegetable farmers inSoutheast Asia. In: P. T. Haskell and P. McEwen (eds) Ecotoxicology: Pesticides and Beneficial Organisms. Chapman & Hall, London, pp.404-409.

Vuong, L. V., Bich, M. T., Son, D. V., Bregman, L. and Gallagher, K. 1995. Evaluation Report: Tea IPM Development Program in Bac Thai Province. Nov 20-Dec 1, 1995. CIDSE, Hanoi, 24 pp.

Waage, J. K. 1989. The population ecology of pest - pesticide - natural enemy interactions. In: P. C. Jepson (ed.) Pesticides and Non-target Invertebrates. Intercept, Wimborne, U.K., pp. 81-93.

Waibel, H. 1993. Government intervention in crop protection in developing countries. In: D. J. Chadwick and J. Marsh (eds) Crop Protection and Sustainable Agriculture. Wiley, Chisester, pp. 76-93.

Waibel, H. and Engelhardt, T. 1988. Criteria for the economic evaluation of alternative pest management strategies in developing countries. FAO Plant Protection Bulletin, 36, 27-33.

Waibel, H., Fleischer, G., Kenmore, P. E. and Feder, G. 1999. Evaluation of IPM Programs – Concepts and Methodologies. Papers presented at the First Workshop on Evaluation of IPM Programs. Hannover, March 16-18, 1998. Pesticide Policy Project Publication Series No. 8, Hannover, pp. 61.

Waterhouse, D. F. 1998. Biological Control of Insect Pests: Southeast Asian Prospects. ACIAR, Canberra, 548 pp.

Way, M. J. 1963. Mutualism between ants and honeydew producing Homoptera. Annual Review of Entomology, 8, 307-344.

Way, M. J. 1990. Constraints on IPM implementation. Extract from report submitted to the international pest management task force, pp. 65-94.

Way, M. J. and Khoo, K. C. 1991. Colony dispersion and nesting habits of the ants, *Dolichoderus thoracicus* and *Oecophylla smaragdina* (Hymenoptera: Formicidae) in relation to their success as biological control agents on cocoa. Bulletin of Entomological Research, 81, 341-350.

Way, M. J. and Khoo, K. C. 1992. Role of ants in pest management. Annual Review of Entomology, 37, 479-503.

Way, M. J., Cammell, M. E., Bolton, B. and Kanagaratnam, P. 1989. Ants (Hymenoptera: Formicidae) as egg predators of coconut pests, especially in relation to biological control of the coconut caterpillar, *Opisina arenosella* Walker (Lepidoptera: Xyloryctidae), in Sri Lanka. Bulletin of Entomological Research, 79, 219-233.

Whittle, A. M. 1992. Diseases and pests of citrus in Viet Nam. FAO Plant Protection Bulletin, 40(3), 75-81.

Williamson, S. F. J. 1998. The Asian initiative in pesticides and beneficials testing. In: P. T. Haskell and P. McEwen (eds) Ecotoxicology: Pesticides and Beneficial Organisms. Chapman & Hall, London, pp. 366-371.

Zadoks, J. C. 1985. On the conceptual basis of crop loss assessment: the threshold theory. Annual Review of Phytopathology, 23, 455-473.

Summary

Since the late 1980s, fruit production in the Mekong Delta, Vietnam, has become increasingly important because the government changed its policy towards a more market-oriented economy with better land tenure security for individual farmers, them having more freedom in land use allocation, the purchase of inputs and the marketing of their agricultural produce. Orchards are mainly converted paddy fields, being established on raised beds interspersed with canals. Concern over the sky-rocketing presence of agrochemicals in fruit production, prompted the need for evaluating traditional knowledge, and more broadly farmers' knowledge, perceptions and practices (KPP) in pest management. Widespread gaps in farmers' knowledge, as well as farmers' perception of high input use and promotion of pesticides can influence decisions to practice rational pest management.

In this work the systems approach has been followed. Rather than solely aiming at reduced chemical inputs, integrated pest management (IPM) should give proper account to the whole farming system with due consideration to the historical, institutional, socio-economic and agronomic context of fruit production systems (**Chapter 1**). Habitat manipulation or conservation biological control means the provision of resources, such as food and shelter, to natural enemies to improve their effectiveness at controlling pests. In the Mekong Delta, fruit farmers traditionally manipulate their agro-ecosystem to improve biological control with the black ant *Dolichoderus thoracicus* and the weaver ant *Oecophylla smaragdina*. Overall, farmers' KPP was evaluated with the objectives:

(1) to document farmers' traditional pest management practices;
(2) to define gaps between farmers' KPP and scientific knowledge in pest management;
(3) to set research agendas;
(4) to improve the design and effectiveness of training programmes.

Each of these objectives has been discussed throughout the different chapters of this thesis covering mango (*Mangifera indica*), sapodilla (*Manilkara zapota*) and citrus (*Citrus* spp.) production systems in Can Tho, Dong Thap, Tien Giang and Tra Vinh Province of the Mekong Delta.

A survey of farmers' KPP in pest management in mango revealed that the identification and control of pests was often preventive or based on damage symptoms rather than on sighting causal agents (**Chapter 2**). Because mango trees often grow 8 m high or more pest monitoring is seriously hampered. Damage of the mango seed borer *Deanolis albizonalis* was often wrongly attributed to the fruit fly *Bactrocera dorsalis*, a situation which has recently improved due to extension and media activities. Clearly, tree

formation by pruning and lopping could improve farmers' observation, stressing the importance of broadening farmer training from integrated pest management to integrated crop management. As for rice, also mango farmers targeted leaf-damaging insects, although *D. albizonalis* and the flower-sucking hoppers *Idioscopus* spp. received most target sprays. Nearly all farmers applied calendar sprays of insecticides (97%) and fungicides (79%) from pre-flowering until harvest, most of them spraying 12 times per year. About 20% of the insecticides used belonged to Toxicity Class I according to the World Health Organization, the rest nearly all belonged to Class II. Half of all the target sprays were done with three pyrethroid products only. General linear model analyses were conducted to find out which production characteristics and pesticide information sources discriminated best for differences in the number of pesticide products and sprays applied. Only information sources seemed to be significant. More different pesticide products were applied by farmers getting pesticide advice from the extension staff or media. Farmers getting advice from the Extension Service, for mango being mainly important in Tien Giang Province for about 30% of the farmers, sprayed less frequently, but overall sprayload was not influenced. Farmers' sprayload was higher for those relying on their own experience or the pesticide seller. Expenditure for pesticides was correlated with that of fertilizers. There was no relationship between the amount of money spent on pesticides and yield. Only 10% of the 93 participating farmers knew about natural enemies, all of which were predators.

As opposed to mango, farmers cultivating sapodilla have a long tradition of biological pest control, with the majority (61%) considering the black ant *D. thoracicus* as beneficial in decreasing damage by the fruit borer *Alophia* sp. (51%) and the mealybug *Planococcus lilacinus* (43%) (**Chapter 3**). In orchards where *D. thoracicus* were present, 25% fewer farmers sprayed insecticides than farmers without *D. thoracicus*. Some farmers interplanted their crop with banana plants, which offer good ant nesting sites. Promoting greater farmers' acceptance of *D. thoracicus* may be difficult, because 30% of the farmers said that *D. thoracicus* increases mealybug populations. So far, *D. thoracicus* has been only thoroughly studied in cocoa, and for biological control to be effective abundant, well-distributed ant populations are needed, requiring a mutualistic relationship with honeydew-producing mealybugs. In our experiments at six different locations, *Alophia* sp. populations were significantly smaller in ant-abundant trees. However, contrary to what would be expected, the mealybug *P. lilacinus* was not affected. It is postulated that the mealybug populations were rather low throughout the fruiting season, because from time to time farmers poured a sugar solution around the tree bases to attract and feed the ants, and as such eliminating the unique dependency of *D. thoracicus* on honeydew-producing

Homoptera. Further investigations of how farmers' crop management practices can interfere with this mutualistic relationship offer great potential for applications of this ant as biological control agent in fruit crops in SE Asia.

Crop management practices may also negatively affect the population build-up of the ant. As opposed to Can Tho where irrigation water is bailed on the planting beds, in Tra Vinh Province the use of high-pressure pumps to spray tree canopies with water hampered *D. thoracicus*, therefore lessening *Alophia* sp. control. Farmer-to-farmer training and mass media campaigns about the beneficial effect of *D. thoracicus* should be conducted to promote wider use of this ant species as a biological control agent and to reduce pesticide use in sapodilla orchards.

In **Chapter 4**, the different techniques used by citrus farmers in Can Tho and Dong Thap Province to manage the weaver ant *Oecophylla smaragdina* were presented. Farmers practicing ant husbandry were older than those not doing so. Husbandry of *O. smaragdina* involves obtaining and establishing ant colonies, providing food and refuge for the ants, placing bridges between trees and protecting established colonies from competing ant species. Although no quantitative data were collected, we observed many *O. smaragdina* nests in non-crop vegetation within or closely surrounding the orchard. These nests are of utmost importance for the surviving of a colony when pesticides are applied and for recolonization of the orchard between successive pesticide applications. Nearly all pesticides available on the market were deleterious to ants, and therefore avoiding pesticide applications as much as possible is also an important conservation strategy. In orchards with *O. smaragdina*, farmers indeed sprayed less frequently and used fewer insecticides that are highly hazardous. Nevertheless, since the last 10 years the increasing input of agrochemicals is threatening this traditional practice of *O. smaragdina* husbandry. In 1998, about 75% of the sweet orange (*Citrus sinensis*) and only 25% of the Tieu mandarin (*C. reticulata*) orchards had large *O. smaragdina* populations, due to a lower pesticide pressure in the first crop. The majority of sweet orange farmers sprayed insecticides only twice per year, compared to 9 times per year for those growing Tieu mandarin. It is often presumed and advertized that a high input of pesticides increases the yield, a statement already proven invalid for mango production systems (see Chapter 2). Similarly for citrus, expenditure on pesticides was reduced by half when *O. smaragdina* was abundant, without affecting either the yield or the farmers' income. Therefore, weaver ant husbandry is a good example of a traditional practice which should be further promoted as an important component of sustainable citrus production. The experience of those farmers that use no or few pesticide should be drawn upon in developing farmer training programmes or mass media tools to promote IPM in citrus.

Consequently we evaluated the influence of weaver ants on citrus farmers' perception of pests (**Chapter 5**). With a three-level scale (low, moderate and high) farmers assessed insect pest incidence and severity, as well as yield loss caused by the major insect pests and diseases. Farmers generally attributed higher yield losses to diseases than to insects. Sweet orange farmers graded the yellow leaf symptom or citrus greening disease as causing highest yield loss, whereas black spot caused by *Guignardia citricarpa* was most important in Tieu mandarin. Regarding insect pests, lower ratings of infestation could be directly or indirectly attributed to the presence of *O. smaragdina*. A direct positive effect on pest reduction can be claimed to its predatory behaviour. The indirect beneficial effect is that most farmers consciously use less pesticide when *O. smaragdina* is present in their orchard (see Chapter 4), as such creating a better environment for the survival of other beneficial organisms. The number of insecticide sprays targeting a particular pest was positively correlated both with pest incidence and severity and negatively correlated with ant abundance.

Irrespective of the citrus cropping system, farmers with *O. smaragdina* assessed lower infestation by the leaf-feeding caterpillars *Papilio* spp. and the aphids *Toxoptera aurantii* and *T. citricidus* than those without ants. Infestation by the mealybug *Planococcus citri* was not rated different. Nearly all farmers mentioned the citrus leafminer *Phyllocnistis citrella* and the citrus stinkbug *Rhynchocoris humeralis* as important citrus pests. Although in sweet orange the incidence of *P. citrella* was rated lower by farmers with ants, this pest remained a major spray target because of the high visibility of its damage symptoms. In sweet orange, yield loss due to *R. humeralis*, on the other hand, was rated lower and hence they were considered a less important spray target when ants were abundant. The citrus red mite *Panonychus citri* was the most important target in Tieu mandarin, accounting for more than 30% of all target sprays. Stimulating *O. smaragdina* as a biological control agent in Tieu mandarin will only be successful when mites can be controlled simultaneously without excessive chemical treatments. The concept of ant predation, well known by most farmers, could be used as a starting point to educate farmers about the existence and role of predatory mites.

Because of the growing importance of the agrobusiness, not only the type of cropping system, farmers' crop management practices or whether they practice ant husbandry influence farmers' KPP in pest management, also pesticide information sources have become increasingly important. This influence was assessed for citrus in **Chapter 6**. In the intensive Tieu mandarin cropping system, media and extension activities increased farmers' knowledge of difficult-to-observe pests such as the citrus red mite *Panonychus citri* and thrips, *Thrips* sp. and *Scirtothrips* sp. Since extension was weak in sweet orange, those farmers exposed to media only reported the damage symptom of mites, not knowing the causal agent. Media alone seemingly did not suffice to acquaint farmers with these small organisms. Differently as for mango, where the number of pesticide products and sprays was only influenced by the type of pesticide information source, for citrus also the production region and the type of cropping system was important. More different pesticide products were applied by farmers from Lai Vung District, Dong Thap Province than those from Can Tho Province, and by those getting pesticide advice from the media or staff from the Cantho University. Farmers getting advice from the media pesticide advertisements applied more different products, and sprayed insecticides more frequently, whereas the extension has stimulated the use of acaricides and increased the number of both insecticide and fungicide sprays. The traditional practice of biological control with the ant *Oecophylla smaragdina* might be endangered with growing media influence and when extension activities remain confined to chemical pest control.

Despite having great potential for being incorporated in intensively managed, integrated fruit production systems, generalist predators like ants can not control all the pests occurring in orchards. The citrus leafminer *Phyllocnistis citrella* and the citrus red mite *Panonychus citri*, for instance, are major pests in both sweet orange and Tieu mandarin, irrespective of the presence of ants. In Vietnam, no information is available about the taxonomy and/or impact of their endemic natural enemies. Nevertheless, based on literature, insights in the agricultural landscape of the Mekong Delta, and farmers' use and management of the orchard ground cover, some small modifications of habitat manipulation have been suggested for further testing (**Chapter 7**). Considering the agricultural mosaic of the Mekong Delta, where orchards are often interspersed between the paddy fields, it is adviseable to avoid a grassy orchard ground cover. After citrus farmers harvest their fruit in the dry season, they clear the canals in the orchard, adding the sediments on top of the planting beds and as such destroying all the weeds. Irrigation is halted for about two weeks, followed by a period of frequent irrigation to induce flushing and flowering of the citrus trees. According to farmers' perception of the damage caused throughout the year, populations of the leafminer *P. citrella* are aggrevated after times when the weed flora has been completely destroyed, probably because beneficial organisms are deprived from refuge and food.

Problems with the citrus red mite may also become worse after clearing the orchard ground cover. In China, the asteraceous weed *Ageratum conyzoides* is cultivated as ground cover since it is the most important pollen and nectar producing plant, enhancing predatory mites. Besides, pollen are an important supplementary food source for ladybeetles, whereas lacewings seem to prefer composite flowers for their nectar. These insects are important predators of aphids, mealybugs and scales. IPM training programmes could include learning farmers about other natural enemies like predatory mites, as well as to recognize available asteraceous weeds such as *A. conyzoides, Blumea glandulosa* and *Eclipta prostrata* as potentially beneficial weeds. Small adjustments of current weed management techniques, like adding the sediments on alternate beds every other year, or adding them only around the tree base, are suggested for future testing to improve availability of pollen and nectar for beneficials at crucial moments in the cropping season. On-site research is required to avoid running the risk that promotion of certain weeds enhances problems with specific insect pests or diseases.

In **Chapter 8**, farmers' KPP related to pests, natural enemies, pest management and habitat manipulation is synthesized and discussed, stressing strengths and bottlenecks for the development of IPM fruit programmes. In the Mekong Delta, individualism and competition between fruit farmers is quite strong. Those farmers who have knowledge about natural enemies have learnt this only by observing their own orchard, and exchange of this kind of information is very limited. Methods should be developed to positively use farmers' attitude towards competition in the development of IPM, rather than to look at it as a constraint. Instead of focusing on the performance of one individual farmer, which happens nowadays, better would be to organize contests between groups of farmers, for instance between different villages or districts. An 'IPM village of the year award' could be a good tool for improving extension-community interactions. Also the establishment of 'weaver ant clubs' offers great potential for farmer empowerment.

Increased knowledge of difficult-to-observe pests does not necessarily make farmers better decision-makers, but can also lead to higher pesticide use, as noticed in Dong Thap after farmers had learned about the existence of mites. In those cases where the farmer has been denied the necessary information, it is not the farmer but the extension officer, scientist or media who is the decision-maker. The concept of ant predation, well-known by most farmer, should be used as a starting point to learn farmers about the existence and role of predatory mites and ladybeetles.

Staff from the Extension Service or Plant Protection Department, however, often lack knowledge of the fruit agro-ecosystem in general, and of fruit IPM in particular. Feeling confident about the technical, scientific background was seemingly a prerequisite for trainers to become facilitators instead of lecturers sticking to a well-defined agenda. Because in

Vietnam, there exists a general lack of information, and especially of information based on local conditions, it is suggested that the trainers benefit from farmers' experience in developing technical recommendations, rather than waiting for scientific data to be presented in ready-made advice.

The government has an important role to play in the research and development of IPM fruit programmes. To provide farmers with a basket of options, redirecting research in pest control from chemically-based to biologically-based, sustainable solutions is a must. The recent banning of highly toxic insecticides and the registration of IPM compatible petroleum spray oils is a promising step in the right direction. However, implementation of pesticide regulation is still weak. One way to increase farmer's net return with reduced pesticide use is to add external costs to the actual costs of pesticides. These external costs should compensate for human health problems and environmental hazards. The price paid for a pesticide would therefore be the social, rather than the private cost. The extra income from taxes could be used to support IPM activities. Ultimately, an economic evaluation of the importance of beneficial organisms in pest management should be included in the pesticide pricing policy, and tests on pesticide effects on indigenous biological control agents should be build into the registration process for chemical pesticides.

Only an integrated approach with equal attention being paid to developing solutions at the farm and policy level has a proper chance of contributing to a more profitable and sustainable agriculture, reduced risks of human intoxications, and a better environment for the Vietnamese people of today and tomorrow.

Samenvatting

Sinds het einde van de jaren 1980 is de fruitproductie in de Mekong Delta, Vietnam, sterk toegenomen na het invoeren van het vrijemarktmechanisme, waarbij individuele boeren betere landrechten verwierven. Ze konden zelf beslissen over welke teelt ze zouden verbouwen, en ze hadden bovendien een grotere flexibiliteit in het aanschaffen en verkopen van landbouwproducten. Door het aanleggen van plantbedden met kanalen ertussen werden rijstvelden veelal omgevormd tot boomgaarden. De enorme stijging in het gebruik van chemische middelen leidde tot de noodzaak om de traditionele kennis van boeren, en meer in het algemeen de kennis, perceptie en praktijken (KPP) in gewasbescherming, te evalueren. Een gebrekkige kennis, alsmede de overtuiging dat het overvloedig gebruik van chemicaliën positief is - een gevoel dat nog versterkt wordt door de campagnes ter bevordering van het gebruik van pesticiden - zijn factoren die een beredeneerde gewasbescherming in de weg staan.

In dit proefschrift werd gekozen voor een holistische benadering. Behalve met het streven naar een verminderd gebruik van agrochemicaliën, dient geïntegreerde gewasbescherming (IPM) rekening te houden met het gehele landbouwproductiesysteem, inclusief de historische, institutionele, socio-economische en landbouwkundige context (**Hoofdstuk 1**). Een evaluatie van de KPP van de boeren werd uitgevoerd om:

(1) de traditionele kennis van boeren met betrekking tot gewasbescherming te illustreren;

(2) de overeenkomsten en verschillen te definiëren tussen de kennis van de wetenschap en die van de boeren;

(3) onderzoeksprioriteiten vast te leggen;

(4) landbouwvoorlichtingsprogramma's op te stellen;

(5) de efficiëntie van deze programma's te verbeteren.

Elk van deze objectieven werd behandeld doorheen de verschillende hoofdstukken van dit proefschrift. De productiesystemen die behandeld worden zijn die van mango (*Mangifera indica*), sapodilla (*Manilkara zapota*) en citrus (*Citrus* spp.) in de provincies Can Tho, Dong Thap, Tien Giang en Tra Vinh.

Door een enquête naar de KPP in gewasbescherming van mangoboeren werd duidelijk dat de identificatie van plagen eerder gebaseerd was op schadesymptomen dan wel op het zien van de schadeverwekker en dat de bestrijding veelal preventief was of slechts plaatsvond na het observeren van schade (**Hoofdstuk 2**). Doordat mangobomen meer dan acht meter hoog kunnen worden, is de identificatie en bemonstering van plagen

erg moeilijk. Zo werd de schade veroorzaakt door de mangozaadboorder *Deanolis albizonalis* soms toegeschreven aan de fruitvlieg *Bactrocera dorsalis*, een situatie die recentelijk verbeterd is door media- en voorlichtingsactiviteiten. Beperken van de grootte van de bomen door snoei- of andere technieken zou het observeren en bemonsteren aanzienlijk vereenvoudigen, wat de noodzaak illustreert om het concept van de geïntegreerde gewasbescherming uit te breiden naar geïntegreerde gewasproductie. Net zoals rijstboeren beschouwden ook mangoboeren (en andere fruitboeren, zie verder) bladetende insecten als schadelijk, hoewel *D. albizonalis* en de bloemenzuigende cicaden *Idioscopus* spp. de meeste bespuitingen kregen. Bijna alle boeren spoten op kalender basis van net voor de bloei tot aan de oogst met insecticiden (97%) en fungiciden (79%). Het merendeel diende 12 maal per jaar bestrijdingsmiddelen toe. Ongeveer 20% van de bespuitingen gebeurde met extreem toxische producten, volgens de Wereldgezondheids-organisatie geclassificeerd als Toxiciteitklasse I producten, en de rest van de toepassingen gebeurde praktisch allemaal met Klasse II producten, die matig toxisch zijn. De helft van alle bespuitingen van alle boeren werd met slechts drie pyrethroiden gedaan. Met lineaire modellen werd bepaald welke productiekarakteristieken en/of informatiebronnen voor het gebruik van pesticiden een bepalende invloed hadden op het aantal toegepaste producten en bespuitingen. Slechts enkele informatiebronnen waren van belang. Meer verschillende producten werden gebruikt door boeren die advies kregen van de media of van landbouwvoorlichters. Het aantal gerichte bespuitingen was het hoogst door boeren die zich op hun eigen ervaring of op advies van de pesticidenverkoper baseerden. De totale uitgaven voor pesticiden was gecorreleerd met die gedaan voor kunstmest. Er was geen relatie tussen de opbrengst en de hoeveelheid geld besteed aan pesticiden. Op een totaal van 93 boeren had slechts 10% enige notie van natuurlijke vijanden; deze nuttige insecten waren allemaal predatoren.

In tegenstelling tot mangoboeren, hebben sapodillaboeren een lange traditie in het toepassen van biologische bestrijding, het merendeel (61%) van hen beschouwden de zwarte mier *Dolichoderus thoracicus* als nuttig voor de bestrijding van de vruchtboorder *Alophia* sp. (51%) en de wolluis *Planococcus lilacinus* (43%) (**Hoofdstuk 3**). In boomgaarden met deze zwarte mieren gebruikten 25% minder boeren pesticiden dan in boomgaarden zonder mieren. Sommige boeren maakten gebruik van een tussenteelt van bananen, omdat dit gewas ideale nestplaatsen biedt voor de zwarte mier en dus verantwoordelijk is voor een betere biologische bestrijding. Een betere algemene acceptatie van deze mier als natuurlijke vijand zou waarschijnlijk problemen opleveren, want ongeveer 30% van de boeren beweerden dat ze bij aanwezigheid van deze mier meer problemen hadden met wolluizen. Dat er een wedezijdse relatie bestaat tussen *D. thoracicus* en wolluizen werd reeds eerder aangetoond in cacaoplantages. Bij experimenten in boomgaarden van boeren op zes verschillende locaties was er steeds minder schade van de vruchtboorder bij aanwezigheid van de mier, doch de wolluispopulaties werden niet beïnvloed, in tegenstelling tot wat verwacht werd. Een hypothese werd geformuleerd dat de wolluispopulaties in de experimenten laag bleven omdat de sapodillaboeren op regelmatige tijdstippen een suikeroplossing rondom de stam van de bomen goten om de mieren te lokken en te voeden, wat de afhankelijke relatie met de suikerafscheidende wolluizen minder stringent zou maken. Het verder bestuderen van hoe teelttechnische maatregelen deze - voor fruitboeren negatieve geachte - relatie zou kunnen beïnvloeden, kan bijdragen tot een toenemend gebruik van deze mier in de fruitproductie in andere Zuidoost-Aziatische landen.

Teelttechnische maatregelen kunnen ook negatief zijn voor mierenpopulaties. Zo besproeiden boeren in de provincie Tra Vinh hun bomen met water onder hoge druk, een techniek door de voorlichtingsdienst aanbevolen als ideaal middel om irrigatie en mechanische bestrijding van insecten te combineren. Dit gaf echter geen voldoende bescherming en ook de opbouw van mierenpopulaties werd hierdoor verhinderd, zodat de boeren uiteindelijk meer en meer pesticiden gingen spuiten. Uitwisseling van informatie tussen boeren en het starten van mediacampagnes omtrent de positieve invloed van de zwarte mier dient gestimuleerd te worden om het pesticidenverbruik te verminderen.

In **Hoofdstuk 4** worden de verschillende technieken behandeld die citrusboeren in de provincies Can Tho en Dong Thap toepassen om de mier *Oecophylla smaragdina* te gebruiken. Deze mier bouwt haar nesten in de bomen door levende bladeren aan elkaar te weven. Boeren die gebruik maakten van *O. smaragdina* waren doorgaans ouder dan de rest. De gehanteerde technieken verschilden soms van boer tot boer en bestonden uit het verzamelen en inbrengen van mierenkolonies, het voorzien van voedsel en schuilplaatsen, het onderling verbinden van bomen met stokken of draden om de distributie van de mieren in de boomgaard te verbeteren, alsook het beschermen van bestaande mierenkolonies tegen concurrerende mierensoorten. Hoewel geen kwantitatieve data werden ingezameld, werden veel mierennesten waargenomen in niet-vruchtbomen rondom de boomgaard. Deze nesten zijn van groot belang voor de overleving van de kolonie indien pesticiden worden toegediend, of voor de herkolonisatie van de boomgaarden na opeenvolgende pesticidentoepassingen. Aangezien praktisch alle op de markt beschikbare pesticiden schadelijk zijn voor mieren, is het vermijden van chemische bestrijding een belangrijke conservatietechniek. In boomgaarden met mieren werden minder extreem toxische producten gebruikt en was ook de spuitfrequentie aanzienlijk lager. Toch vormt het stijgende gebruik van agrochemicaliën gedurende de laatste tien jaren een belangrijke bedreiging voor deze traditionele praktijk. In 1998 hadden ongeveer 75% van de boomgaarden met zoete sinaasappel (*Citrus sinensis*) en slechts 25% van de boomgaarden met Tieu mandarijn (*C. reticulata*) grote mierenpopulaties, dit vooral door het aanzienlijk lager pesticidengebruik door sinaasappelboeren. Het merendeel van hen diende slechts tweemaal per jaar bestrijdingsmiddelen toe, vergeleken met 9 keer per jaar door mandarijnboeren. Het is een gangbare veronderstelling, die ook dikwijls in advertenties gehanteerd wordt, dat een hoger pesticidenverbruik tot hogere opbrengsten leidt. Dat dit niet altijd het geval is werd reeds aangetoond voor mango (Hoofdstuk 2). Zo ook besteedden citrusboeren met mieren in hun boomgaard slechts de helft van het budget aan pesticiden vergeleken met boeren zonder mieren, zonder dat de opbrengst of hun netto inkomen beïnvloed werd. Het gebruik van *O. smaragdina* levert een goed voorbeeld van een traditionele techniek die verder uitgewerkt dient te worden als een belangrijke component van geïntegreerde citrusproductie. Voor de ontwikkeling van citrus IPM-mediacampagnes en opleidingsprogramma's voor boeren zou geput dienen te worden uit de ervaring van deze boeren die geen of nauwelijks pesticiden gebruiken.

Vervolgens werd de invloed van de wevermier nagegaan op de perceptie van plagen door citrusboeren (**Hoofdstuk 5**). Op een schaal met drie niveaus (laag, matig, hoog) schatten boeren het voorkomen en de ernst van plagen in, alsook het opbrengstverlies te wijten aan de belangrijkste plaaginsecten en ziekten. Boeren schreven doorgaans hogere opbrengstverliezen meer toe aan ziekten dan aan insecten. Voor sinaasappelboeren bleek *greening* de belangrijkste bacterieziekte, terwijl de zwartevlekkenziekte veroorzaakt door de schimmel *Guignardia citricarpa* het belangrijkst was in Tieu mandarijn. Wat schadelijke insecten betreft kan de lagere inschatting van aantasting door boeren met *O. smaragdina* direct of indirect toegeschreven worden aan de aanwezigheid van deze mieren. Een directe reductie kan toegeschreven worden aan het predator-effect. Het indirecte effect is dat boeren met mieren bewust minder pesticiden gebruiken (Hoofdstuk 4) waardoor er betere omstandigheden zijn voor het overleven van andere nuttige organismen. Het aantal bespuitingen gericht tegen een bepaald insect was positief gecorreleerd met zowel het voorkomen als de ernst van de plaag, en negatief met de aanwezigheid van *O. smaragdina*.

Onafhankelijk van het type productiesysteem schatten citrusboeren met mieren de aantasting van bladetende rupsen *Papilio* spp. en de luizen *Toxoptera aurantii* en *T. citricidus* lager in dan boeren zonder mieren in hun boomgaard. Wolluisaantastingen

(*Planococcus citri*) werden niet verschillend beoordeeld. Bijna alle boeren beschouwden de citrusbladmineerder *Phyllocnistis citrella* en de citruswants *Rhynchocoris humeralis* als belangrijke plagen. Hoewel in sinaasappelboomgaarden het voorkomen van *P. citrella* lager ingeschat werd door boeren met mieren, bleef dit insect een belangrijk spuitdoelwit gezien het duidelijke schadebeeld. Het opbrengstverlies in sinaasappel toegeschreven aan *R. humeralis*, werd lager ingeschat en eveneens minder als spuitdoelwit beschouwd in boomgaarden met mieren. De rode citrusmijt *Panonychus citri*, waartegen 30% van alle bespuitingen in Tieu mandarijn gericht was, was in dit gewas het belangrijkste spuitdoelwit. Het bevorderen van *O. smaragdina* als biologisch bestrijdingsmiddel in Tieu mandarijn kan alleen met succes toegepast worden indien tevens het mijtenprobleem opgelost kan worden zonder overvloedig gebruik te maken van chemische middelen. Het concept van predatie door mieren is alom bekend bij citrusboeren en zou als uitgangspunt kunnen dienen om boeren te informeren over het bestaan en de rol van roofmijten.

Door het toenemende belang van de agro-industrie wordt de kennis en perceptie van boeren met betrekking tot gewasbescherming niet alleen beïnvloed door het productiesysteem, de teelttechnieken, of het feit of boeren al of niet mieren houden in hun boomgaarden, maar eveneens door de diverse informatiebronnen over pesticiden. Deze laatstgenoemde invloed werd bestudeerd voor citrus (**Hoofdstuk 6**). In het intensieve Tieu mandarijnteeltsysteem hebben media en voorlichtingsactiviteiten bijgedragen tot een betere kennis van de boeren over moeilijk te observeren organismen zoals de rode citrusmijt *Panonychus citri* en de tripsen *Thrips* sp. en *Scirtothrips* sp. Omdat de voorlichtingsdienst weinig doet voor sinaasappelboeren, meldden deze boeren, die slechts pesticidenadvies kregen via de media, enkel de schadesymptomen van mijten zonder echter de schadeverwekker te kennen. De media als enige informatiebron was blijkbaar niet voldoende om boeren vertrouwd te maken met deze kleine organismen. Hoewel het aantal pesticidenproducten en -bespuitingen bij mangoboeren enkel afhankelijk was van het soort informatiebron, had voor citrus ook de productieregio en het type teeltsysteem een invloed. Het grootst aantal producten werd gebruikt door boeren van het Lai Vung district in de provincie Dong Thap, en door hen die zich voor advies baseerden op de media of op het personeel van de Cantho universiteit. Zij die zich lieten voorlichten door de media spoten frequenter met insecticiden, terwijl zij die zich baseerden op advies van de voorlichtingsdienst meer acariciden gebruikten en meer bespuitingen met insecticiden en fungiciden uitvoerden. Het traditionele gebruik van biologische bestrijding met de mier *O. smaragdina* wordt bedreigd indien de media nog meer aan invloed wint, en indien de activiteiten van de voorlichtingsdienst zich beperken tot chemische bestrijding van plagen en ziekten.

Hoewel de mier *O. smaragdina* een groot potentieel heeft om toegepast te worden in het intensieve mandarijnteeltsysteem, kunnen algemene predatoren zoals mieren niet alle schadelijke organismen in bedwang houden. De citrusbladmineerder *Phyllocnistis citrella* en de rode citrusmijt *Panonychus citri* zijn belangrijke plagen in zowel mandarijn- als sinaasappelboomgaarden onafhankelijk van de aanwezigheid van mieren. In Vietnam is er echter geen wetenschappelijke informatie voorhanden omtrent de taxonomie en/of de impact van hun natuurlijke vijanden. Gebaseerd op literatuur, verworven inzichten in het diverse rurale landbouwlandschap, en het gebruik en beheer van de ondergroei van de boomgaarden door de lokale boeren, werden een aantal kleine aanpassingen gesuggereerd om de biologische bestrijding van deze plagen te verbeteren (**Hoofdstuk 7**). Aangezien in het landbouwlandschap van de Mekong Delta boomgaarden en rijstvelden samen voorkomen, is het af te raden om bij fruitboeren een ondergroei bestaande uit grassen aan te bevelen. Na het oogsten van citrus in het droge seizoen, baggeren de boeren de kanaaltjes tussen de plantbedden. Het slib wordt op de plantbedden aangebracht zodat de volledige kruidenflora vernietigd wordt. Vervolgens wordt er gedurende twee weken niet geïrrigeerd; daarna worden de bomen zeer dikwijls geïrrigeerd om de bloei te induceren. Volgens de waarneming van de boeren is de schade veroorzaakt door de bladmineerder groter na de periode waarin de kanalen schoongemaakt worden. Dit zou mogelijk het geval kunnen zijn, gezien de natuurlijke vijanden van *P. citrella* door deze praktijk minder voedsel en schuilplaatsen hebben.

Problemen met de rode citrusmijt zouden om dezelfde redenen eveneens kunnen toenemen. In China wordt het geitenonkruid *Ageratum conyzoides* (Asteraceae) als bodembedekker toegepast in citrusboomgaarden, aangezien deze de belangrijkste pollen- en nectarproducerende plant is. Behalve voor roofmijten is pollen tevens een belangrijke voedselbron voor lieveheersbeestjes, terwijl composieten ook door gaasvliegen verkozen worden voor hun nectar. Deze insecten zijn belangrijke predatoren van blad-, wol- en schildluizen. Bij trainingen in IPM, kan boeren het bestaan en nut van andere natuurlijke vijanden zoals roofmijten en het potentieel nut van bepaalde planten zoals *A. conyzoides*, *Blumea glandulosa* en *Eclipta prostrata* duidelijk gemaakt worden. Kleine aanpassingen van de huidige onkruidbeheerstechnieken, zoals elk ander jaar de sedimenten aanbrengen op alternerende bedden, of deze enkel toedienen rondom de basis van de bomen, zouden verder dienen te worden bestudeerd om de beschikbaarheid van pollen en nectar voor nuttige organismen te garanderen op cruciale momenten in het groeiseizoen.

Locatiegebonden onderzoek is vereist om de risico's te vermijden dat het bevorderen van bepaalde planten een toename van bepaalde plagen of ziekten zou veroorzaken.

In **Hoofdstuk 8** werden de KPP van de boeren met betrekking tot plagen en ziekten, natuurlijke vijanden, gewasbescherming, en habitatmanipulatie samengevat en bediscussieerd, met extra nadruk op de sterke en zwakke kanten om een IPM-fruitprogramma te ontwikkelen. In de Mekong Delta is individualisme en competitie tussen fruitboeren vrij sterk aanwezig. Boeren die kennis hadden van natuurlijke vijanden wisten dit alleen doordat ze observaties hadden gedaan in hun eigen boomgaard. Onderlinge uitwisseling van informatie omtrent zowel biologische als chemische bestrijding is uiterst gering. Er zouden manieren dienen gevonden te worden bij de ontwikkeling van IPM-programma's om deze competitieve houding positief te benutten. In plaats van naar de *performance* van een enkele boer te kijken, hetgeen heden ten dage gebeurt, zou het beter zijn om bijvoorbeeld IPM-wedstrijden te organiseren tussen groepen van boeren, bijvoorbeeld tussen verschillende dorpen of districten. Een 'IPM-dorp van het jaar' prijsuitreiking kan een goede manier zijn om de samenwerking tussen de voorlichtingsdiensten en de boerengemeenschappen te bevorderen. Zo ook zou het opstarten en organiseren van 'mierenclubs' kunnen bijdragen tot een sterkere positie van de boer en tot een betere uitwisseling van informatie.

Een betere kennis van moeilijk te observeren organismen maakt boeren niet *per se* besluitvaardiger, omdat het ook tot een verhoogd pesticidenverbruik kan leiden; dit was het geval in de provincie Dong Thap, nadat boeren geleerd hadden wat mijten waren. Wanneer de boer niet over voldoende informatie beschikt, zal niet hij maar de landbouwvoorlichter, de media of de pesticidenverkoper de beslissingen naar hun hand zetten. Het concept van predatie door mieren is alom bekend bij fruitboeren en zou aangewend dienen te worden om boeren op de hoogte te brengen van andere predatoren zoals roofmijten en lieveheersbeestjes.

Het personeel van de voorlichtings- en gewasbeschermingsdienst heeft dikwijls weinig kaas gegeten van fruitproductie in het algemeen en van IPM in fruit in het bijzonder. Zich vertrouwd voelen met de technische en wetenschappelijke achtergrond was blijkbaar een voorwaarde voor de voorlichters om te willen werken volgens het concept van '*learning by doing*', en dus om af te stappen van het louter geven van voordrachten binnen een strak omlijnde agenda. Aangezien er in Vietnam een algeheel gebrek is aan informatie, en zeker aan informatie gebaseerd op lokale omstandigheden, wordt voorgesteld dat de voorlichters de ervaring van de boeren ten gunste gebruiken om technische aanbevelingen te formuleren, veeleer dan te wachten op klaargestoomde adviezen gebaseerd op wetenschappelijk onderzoek.

Ook de overheid heeft een belangrijke rol te spelen in het stimuleren van onderzoek en de uitwerking van IPM-programma's. Om boeren te voorzien van een waaier aan gewasbeschermingstechnieken en –methoden is het nodig om het onderzoek om te buigen van chemische bestrijding naar biologisch en ecologisch georiënteerde bestrijding. Het recentelijk verbannen van extreem toxische insecticiden en het registreren van IPM-compatibele petroleum-spuitoliën zijn reeds stappen in de goede richting. De toepassing van de regelgeving is echter nog zwak. Het toevoegen van externe kosten aan de actuele kosten van pesticiden is een mogelijke oplossing om het netto-inkomen van boeren te verhogen bij een verminderd pesticidenverbruik. De te betalen prijs voor een pesticide zou dan een sociale kostprijs zijn, die problemen met het milieu en de volksgezondheid zou moeten compenseren. Het extra inkomen aan belasting zou door de overheid aangewend kunnen worden om verder IPM-activiteiten te ontwikkelen of te ondersteunen. Bovendien zouden de effecten van pesticiden op inheemse natuurlijke vijanden mee in rekening dienen gebracht te worden bij de registratie van pesticiden.

Enkel een geïntegreerde aanpak waarbij evenveel aandacht wordt geschonken aan oplossingen op het niveau van de boer als op beleidsniveau, biedt een goede kans om bij te dragen tot een rendabele en duurzame landbouw, een verminderd risico voor de menselijke gezondheid, en een betere leefomgeving voor het Vietnamese volk van vandaag en morgen.

List of publications

Some chapters in this thesis are or will be published in a slightly different form as:

Chapter	Publication
2	Van Mele, P., Cuc, N. T. T. and van Huis, A. 2000. Farmers' knowledge, perceptions and practices in mango pest control in the Mekong Delta, Vietnam. International Journal of Pest Management, 45, in press.
3	Van Mele, P. and Cuc, N. T. T. 2000. Farmers' perceptions and practices in use of *Dolichoderus thoracicus* (Smith) (Hymenoptera: Formicidae) for biological control of pests of sapodilla. Biological Control, accepted.
4	Van Mele, P. and Cuc, N. T. T. 2000. Evolution and status of *Oecophylla smaragdina* as pest control agent in citrus in the Mekong Delta, Vietnam. International Journal of Pest Management, 45, in press.
5	Van Mele, P., Cuc, N. T. T. and van Huis, A. 2000. Direct and indirect influences of weaver ant *Oecophylla smaragdina* husbandry on citrus farmers' pest perceptions and management practices. Submitted to International Journal of Pest Management.
6	Van Mele, P., Hai, T. V., Thas, O. and van Huis, A. 2000. Impact of different sources of pesticide advice on citrus farmers' knowledge, perception and practices in pest management, Mekong Delta, Vietnam. Submitted to International Journal of Pest Management.
7	Van Mele, P. and van Lenteren, J. C. 2000. Habitat manipulation for improved control of citrus leafminer and mite pests in a mixed orchard-ricefield landscape, Mekong Delta, Vietnam. Submitted to Agriculture, Ecosystems & Environment.

Additional publications related to the research described in this thesis:

Van Mele, P. 1998. Alternative uses of rice by-products in Vietnam. Humus News, 14(1), 2-3.

Van Mele, P. 1998. Status of IPM in fruit trees in SE Asia. Proceedings of the First Symposium on Fruit Production in the Mekong Delta Focusing on IPM, February 25, 1998, Can Tho, pp. 42-49.

Van Mele, P. and Huynh, N. V. (eds). 1998. Proceedings of the First Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management, February 25, 1998, Can Tho, Vietnam, 120 pp.

Van Mele, P., Kim, P. V., Hai, T. V., Cuc, N. T. T., Sen, L. T., Huynh, N. V. and Coosemans, J. 1998. Fruit production techniques and constraints in Can Tho Province, southern Vietnam. Proceedings of the International Conference of IPM, June 15-20, 1998, Guangzhou, China, p. 350.

Van Mele, P. 1998. Integrated pest management: any news from China? (text in Vietnamese). Science and Technology in Agriculture, 7, 2-4.

Van Mele, P. 1998. Orchard characteristics and agricultural practices of fruit farmers in the Mekong Delta. Technical paper presented to FAO, 11 pp.

Van Mele, P. 1998. Integrated fruit production of mango and durian in the eastern region of Thailand. Report on a short-term evaluation mission of the Thai-German 'IPM in

Selected Fruit Trees' project in Thailand, November 7-12 1998. Vietnamese-Belgian IPM Project Technical Report N°2, 22 pp.
Van Mele, P. 1999. Living fences around orchards in southern Viet Nam. Non-Wood News, 6, 48-49.
Van Mele, P. and Huynh, N. V. (eds). 1999. Proceedings of the Second Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management, March 3, 1999, Can Tho, 170 pp.
Van Mele, P. 1999. The IPM in Fruit Production Project: which way are we going? Proceedings of the Second Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management, March 3, 1999, Can Tho, pp.1-8.
Van Mele, P. 1999. Participatory learning: extension possibilities for IPM in fruit production in Vietnam. Proceedings of the Second Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management, March 3, 1999, Can Tho, pp. 9-20.
Van Mele, P. 1999. IPM in developing countries: only a dream without proper policy? IPMnet NEWS, 63, 5.
Van Mele, P. and Hai, T. V. 1999. Pesticide use in orchards in the Mekong Delta of Vietnam. Proceedings of the 5th International Conference on Plant Protection in the Tropics, Kuala Lumpur, March 15-18, 1999, pp. 529-533.
Van Mele, P. and Cuc, N. T. T. 1999. Predatory ants in orchards in the Mekong Delta of Vietnam. Proceedings of the International Symposium on Biological Control in the Tropics, Serdang, Malaysia, March 18-19, 1999, pp. 118-122.
Cuc, N. T. T. and Van Mele, P. 1999. Beneficial effects of black ants (*Dolichoderus thoracicus* Smith) in sapodilla production in Vietnam. Proceedings of the International Symposium on Biological Control in the Tropics, Serdang, Malaysia, March 18-19, 1999, pp. 29-33.
Van Mele, P. and Phen, T. V. 1999. Utilization and management of orchard ground cover in the Mekong Delta, Vietnam. Proceedings of the 17th Asian-Pacific Weed Science Society Conference, Bangkok, November 22-27, 1999, pp. 296-302.

Other publications:

Van Mele, P. 1992. Een nieuwe techniek om kieming van *Striga* - zaad te testen gebruik makend van waardkiemwortels. M.Sc.Thesis, Ghent University, 126 pp.
Van Mele, P., Van Damme, P. and Berner, D. C. 1992. A new technique to test germination response of *Striga* -seed using host plant roots. Mededelingen van de Faculteit van de Landbouwwetenschappen Ghent University, 53(3b), 993-999.
Van Mele, P. and Anthonysamy, S. 1994. How goats exploit available resources. In: M. K. Vidyadaran and S. C. Quah (eds) Applied Biology Beyond The Year 2000. Proceedings of the 3rd Symposium of Malaysian Society of Applied Biology, May 28-29, 1994, Melaka, pp. 7-9.
Van Mele, P., Davis, M. P. and Halim, R. A. 1994. A fast method to estimate quality and quantity of pasture intake by grazing animals. In: Proceedings of the Second Symposium on Sheep Production in Malaysia, 22th-24 November, 1994, Serdang, Malaysia, pp. 105-106.
Van Mele, P., Anthonysamy, S., Symoens, C. and Beeckman, H. 1994. Feeding time and botanical composition of diets selected by indigenous goats on native pastures in Malaysia. Pertanika Journal of Tropical Agricultural Science, 17(3), 229-237.
Van Mele, P., Van Damme, V., Scheldeman, X., Meylemans, B. and Van Damme, P. 1996. Effect of management practices on the occurrence of *Echinochloa* spp. in Dry and

Intermediate Zone rice fields of Sri Lanka. Mededelingen van de Faculteit van de Landbouwwetenschappen Ghent University, 61(3b), 1115-1121.

Van Mele, P., Meylemans, B. and Van Damme, P. 1996. Floristic composition and relative abundance of rice weeds in the Dry and Intermediate Zones of Sri Lanka. Xth International Symposium on the Biology of Weeds, September 11-13, 1996, Dijon, France, pp. 291-298.

Van Mele, P., Dekens, E. and Gunathileke, H. A. J. 1996. Effect of coir dust mulching on weed incidence in a pineapple intercrop under coconut in Sri Lanka. Mededelingen van de Faculteit van de Landbouwwetenschappen Ghent University, 61(3b), 1175-1180.

Van Mele, P. 1997. Utilization of coconut coir dust mulch in the tropics. Humus News, 13(1), 3-4.

Van Mele, P., Hulsen, K. and Van Damme, P. 1997. Leaf anatomy and morphology of some Mediterranean *Pistacia* spp. Scripta Botanica Belgica, 15, 154.

IPGRI. 1997. Descriptors for pistachio (*Pistacia vera* L.). International Plant Genetic Resources Institute, Rome, 51 pp. (Principal authors: Barone, E., Padulosi, S. and Van Mele, P.)

Van Mele, P., Van Damme, V., Scheldeman, X., Meylemans, B. and Van Damme, P. 1997. Herbicide use and occurrence of *Echinochloa* spp. in rice fields in the Dry and Intermediate Zones of Sri Lanka. International Rice Research Notes, 22(1), 47.

Vromant, K., Van Mele, P., Vromant, N. and Bulcke, R. 1997. Influence of seeding density on weeds in wetland rice in southern Vietnam. Mededelingen van de Faculteit van de Landbouwwetenschappen Ghent University, 62(3a), 851-856.

Padulosi, S., Caruso, T., Barone, E., Van Mele, P. and Kaska, N. 1997. IPGRI'S initiatives for the promotion of better conservation and use of *Pistacia* genetic resources. Proceedings of the Second International Symposium on Pistachios and Almonds, August 24-29, 1997, Davis, California, USA, fruitsandnuts.ucdavis.edu/ishs1.html.

Van Mele, P. 1997. Management of native pastures and dietary intake of small ruminants in the Western Taurus Mountains, Turkey. Mission report for the IUAP 28 'Interdisciplinary Archeology' project in the Sagalassos area (Burdur Province), Turkey, 12 pp. + 5 annexes.

Beuls, I., De Cupere, B., Van Mele, P., Vermoere, M., Vanhecke, L. and Waelkens, M. 1998. Present-day traditional ovicaprine herding as a reconstructional aid for herding at Roman Sagalassos. Proceedings of the 4th International Conference of Archaeozoology of South-West Asia and Adjacent Areas (ASWA), Paris, June 29 – July 3, 1998, in press.

IPGRI. 1998. Descriptors for *Pistacia* spp. (excluding *Pistacia vera* L.). International Plant Genetic Resources Institute, Rome, Italy, 48 pp. (Principal contributors: Kaska, N., Padulosi, S. and Van Mele, P.).

Coosemans, J. and Van Mele, P. 1999. Integrated production of apple and pear in Belgium. Proceedings of the Second Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management, March 3, 1999, Can Tho, Vietnam, pp. 21-26.

Van Mele, P. and Beeckman, H. 1999. Vegetation analysis to study rangeland quality and sources of potential noxious weeds. Proceedings of the 17th Asian-Pacific Weed Science Society Conference, Bangkok, November 22-27, 1999, pp. 745-752.

Van Mele, P., Davis, M. P. and Halim, R. A. 1999. Influence of leucaena supplementation on productivity and grazing activity of goats on *Digitaria setivalva* pasture. Tropical Science, 39, 153-158.

Curriculum vitae

Paul Liliane Jozef Van Mele was born on January 12th, 1968, in Sint-Gillis-Waas, Belgium. From 1986 to 1992 he did his MSc. at the Faculty of Agricultural and Applied Biological Sciences, Ghent University, Belgium. He specialized in Agriculture in Tropical and Subtropical Regions, with major courses on Plant Production, Plant Protection, Ecology and Sociology. In 1991, he received a six-months research fellowship at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, to conduct studies on the parasitic weed *Striga hermonthica*.

In 1993-1994, he worked in the 'Goat and Sheep Husbandry' project, based on behalf of the Ghent University at the Universiti Pertanian Malaysia, Serdang, Malaysia. Working at the interface of small farmers, animals and plant species, he developed a strong interest in practical oriented research that can directly contribute to rural development.

From 1995 to 1997 he gave lectures on 'Plant Production in the Tropics' at the Ghent College and the Ghent University, as well as a guest lecture on 'Agriculture and Ecology in Sub-Sahara Africa' at the Institute for Social Geography, the University of Amsterdam, the Netherlands. For several months he collaborated as a visiting scientist in the 'Weeds in Tropical Annual Food Crops' project at the University of Peradeniya, Sri Lanka, funded by the Belgian Agency for Development Co-operation (BADC). The art of deductive, ecological research was further developed by evaluating rice farmers' practices and linking this to the abundance and composition of weed communities in their fields.

During this three-year period, he also made several short trips to Morocco, Turkey, Israel, Italy and Tunesia within the project 'Establishment of a germplasm collection of Mediterranean *Pistacia*', funded by the European Union, after which he was hired as a consultant for the International Plant Genetic Resources Institute (IPGRI), Rome, Italy. This resulted in the books 'Descriptors for pistachio (*Pistacia vera* L.)' and 'Descriptors for *Pistacia* spp. (excluding *Pistacia vera* L.)'.

From 1997 to 1999 the Catholic University Leuven (KU Leuven), Belgium, appointed him as manager of the project 'Integrated Pest Management in Fruit Production', at the Cantho University, Vietnam, during which preliminary IPM curricula were developed for citrus, mango, durian and longan. During this period he visited several orchards and participated in several international conferences in the Philippines, Malaysia, Thailand and China. It was during these occasions that staff from IRRI and

CABI suggested him to write a PhD thesis on his work experience in Vietnam, which he did in 1999-2000 at the Wageningen University, the Netherlands. Currently, he is working as a Farmer Participatory Training and Research Specialist at CABI Bioscience, U.K.

Appendix

Appendix 1. a. Potential danger[1] of commonly used or promoted insecticides and acaricides in fruit in Vietnam (Source: Jäger, 1995; Biobest, 1998; Anonymous, 1999).

Active ingredient	Trade name	WHO Toxicity Class[2]	Toxicity to bees	Toxicity to fish	Toxicity to predatory mites[3]		Toxicity to *Chrysopa carnea*		Toxicity to Coccinellidae		Toxicity to parasitoids[4]	
					eggs	adults	larvae	adults	larvae	adults	larvae	adults
Acrinathrin	Rufast	IV	-	-	-	-	-	-	-	-	-	-
Alpha-cypermethrin	Cyperalpha, Fastac	II	4	4	4	4	-	-	-	4	4	4
Buprofezin	Applaud	III	1	3	1	2	1	-	-	3	2	1
Carbaryl	Sevin	II	4	4	-	4	4	4	2	4	4	4
Cypermethrin	Cymbush, Sherpa, Ustaad	II	4	4	4	4	3	4	-	4	4	4
Deltamethrin	Decis	II	4	4	4	4	2	4	-	4	4	4
Diazinon	Basudin	II	4	4	1	4	3	4	2	2	4	4
Dichlorvos	DDVP	Ib	4	4	1	4	4	4	-	4	4	4
Dimethoate	Bi 58	II	4	3	4	4	4	4	4	4	4	4
Endosulfan	Thiodan	II	2	4	4	4	1	4	-	4	3	4
Esfenvalerate	Sumi-alpha,	II	*	*	4	4	4	4	-	4	4	4
Ethofenprox	Trebon	IV	2	3	-	-	-	-	-	-	-	-
Fenitrothion	Sumithion	II	4	4	4	4	4	4	-	4	4	4
Fenobucarb	Bassa, Hopcin, Vibasa	II	-	3	-	-	-	-	-	-	-	-
Fenpropathrin	Danitol	II	4	4	4	4	4	4	3	4	4	4
Fenpyroximate	Ortus	-	-	-	-	2	-	-	-	-	-	-
Fenvalerate	Fenkill, Sumicidin	II	4	4	4	4	4	4	-	4	4	4

Appendix 1. a. Continued.

Active ingredient	Trade name	WHO Toxicity Class[2]	Toxicity to bees	Toxicity to fish	Toxicity to predatory mites[3]		Toxicity to *Chrysopa carnea*		Toxicity to Coccinellidae		Toxicity to parasitoids[4]	
					eggs	adults	larvae	adults	larvae	adults	larvae	adults
Hexythiazox	Nissorun	IV	1	2	-	1	2	1	1	1	1	1
Imidacloprid	Admire, Confidor	II	4	2	1	1	4	4	-	4	4	4
Lambda-cyhalothrin	Karate	II	4	4	4	4	2	4	4	4	4	4
Methamidophos	Monitor	Ib	4	3	4	4	4	4	4	4	4	4
Methidathion	Supracide	Ib	4	4	4	4	4	4	-	4	4	4
Methomyl	Lannate	Ib	4	4	4	4	4	4	-	4	4	4
Methyl parathion	Methyl parathion	Ia	4	4	-	-	3	3	-	-	-	-
Monocrotophos	Azodrin	Ib	4	3	4	4	3	3	-	-	4	4
Profenophos	Selecron	II	4	4	-	-	2	3	4	4	-	3
Propargite	Comite	III	2	4	4	3	1	1	-	3	3	3
Teflubenzuron	Nomolt	IV	1	1	1	1	4	3	3	2	1	2
Triazophos	Hostathion	Ib	4	3	4	4	3	4	4	4	4	4

[1] - = No data available, 1 = harmless, 2 = slightly toxic, 3 = moderately toxic, 4 = harmful.
[2] Based on toxicity of the commercial formulations whenever possible, otherwise based on toxicity of the active ingredient: Ia = extremely hazardous, Ib = highly hazardous, II = moderately hazardous, III = slightly hazardous, IV = unlikely to present acute hazard in normal use, - = unclassified. Source: Anonymous, 1999.
[3] Based on toxicity to *Amblyseius* spp. and/or *Phytoseiulus persimilis*.
[4] Based on toxicity to Aphidius spp., Encarsia formosa and/or Trichogramma evanescens.

Appendix 1. b. Potential danger[1] of commonly used or in Vietnam promoted fungicides and acaricides when applied as a spray in fruit in Vietnam (Source: Jäger, 1995; Biobest, 1998; Anonymous, 1999).

Active ingredient	Trade name	WHO Toxicity Class[2]	Toxicity to bees	Toxicity to fish	Toxicity to predatory mites[3]		Toxicity to *Chrysopa carnea*		Toxicity to Coccinellidae		Toxicity to parasitoids[4]	
					eggs	adults	larvae	adults	larvae	adults	larvae	adults
Benomyl	Bendazol, Benlate, Benomyl	IV	1	4	1	3	1	2	-	4	1	1
Carbendazim	Appencarb, Bavistin, Derosal	III, IV	-	3	3	4	1	1	1	1	1	2
Chlorothalonil	Daconil	IV	3	4	1	2	1	1	-	1	1	2
Flusilazole	Nustar	III	1	4	1	1	-	-	-	-	-	2
Fosetyl-aluminium	Aliette	-	1	1	1	2	1	-	1	1	-	1
Hexaconazole	Anvil	IV	-	3	-	1	2	1	2	1	-	1
Iprobenphos	Kitazin	II	-	3	-	-	-	-	-	-	-	-
Iprodione	Rovral, Cantox	III	-	3	1	1	1	1	1	1	1	1
Kasugamycin + copper oxychloride	Kasuran	-	-	-	-	-	-	-	-	-	-	-

Appendix 1. b. Continued.

Active ingredient	Trade name	WHO Toxicity Class[2]	Toxicity to bees	Toxicity to fish	Toxicity to predatory mites[3]		Toxicity to *Chrysopa carnea*		Toxicity to Coccinellidae		Toxicity to parasitoids[4]	
					eggs	adults	larvae	adults	larvae	adults	larvae	adults
Kasugamycin	Kasumin	IV	-	-	-	-	-	-	-	-	-	-
Mancozeb	Dithane, Manozeb, Manzate	IV	1	3	1	3	1	2	1	2	1	3
Metalaxyl	Ridomil	III	-	1	-	3	-	-	-	-	-	1
Propiconazole	Tilt	III	3	4	-	1	1	1	2	-	1	3
Propineb	Antracol	III	1	4	3	4	1	1	3	4	1	4
Sulphur	Microthiol, Kumulus	IV	1	1	-	2	1	1	2	2	2	4
Tiophanate-methyl	Topsin	IV	1	3	2	4	1	1	1	1	2	4
Zineb	Zinep	IV	2	3	1	1	-	1	-	1	1	1
Zineb + bordeaux	Copper zinc	-	-	-	-	-	-	-	-	-	-	-

[1] - = No data available, 1 = harmless, 2 = slightly toxic, 3 = moderately toxic, 4 = harmful.
[2] Based on toxicity of the commercial formulations whenever possible, otherwise based on toxicity of the active ingredient: Ia = extremely hazardous, Ib = highly hazardous, II = moderately hazardous, III = slightly hazardous, IV = unlikely to present acute hazard in normal use, - = unclassified. Source: Anonymous, 1999.
[3] Based on toxicity to *Amblyseius* spp. and/or *Phytoseiulus persimilis*.
[4] Based on toxicity to Aphidius spp., Encarsia formosa and/or Trichogramma evanescens.