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Evolution and status of Oecophylla smaragdina (Fabricius) as a pest control agent in citrus in the Mekong Delta, Vietnam

(*Keywords: Oecophylla*, insecticide use, conservation biological control, citrus, SE Asia)

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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 lower pesticide pressure in the first crop. In orchards with *O. smaragdina*, farmers sprayed less frequently and used fewer highly hazardous insecticides. 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 who use no or few pesticides should be drawn upon in developing farmer training programmes or mass media tools to promote IPM in citrus. Farmers practicing ant husbandry were significantly older than those not doing so.

1. 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 1000 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 has been 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* (McGregor) (Acarina: Tetranychidae) and the citrus rust mite *Phyllocoptruta oleivora* Ashmead (Acarina: Eriophyidae), and to a lesser extent mealybugs (Homoptera: Pseudococcidae) (Van Mele, Cuc and van Huis, unpublished). 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 or completely absent in orchards with abundant ants, compared with 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 (Van Mele, Cuc and van Huis, unpublished).

As traditional farming systems are prone to many external forces, of which the pesticide industry is but one, it is imperative

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to assess farmers' current 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 paper, 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.

2. 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 (Van Mele, Cuc and van Huis, unpublished), the type and frequency of pesticide used, and some economic enquiries such as the annual yield and expenditure for agrochemicals. The questionnaire was pretested 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.

3. Results

3.1. 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 20–30 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 facilitating 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 old and older ($n=46$), compared with 44% in the more recently established orchards ($n=104$) (Pearson $\chi^2=5.62$, $P<0.05$). Farmers practicing ant husbandry were significantly older, 55 years old compared with 45 years (Student's $t=4.59$, $P<0.01$). Educational level of the farmer had no influence on the practice of ant husbandry.

3.2. Evolution of insecticide use and weaver ant status

In the absence of *O. smaragdina* nearly all farmers sprayed insecticides (table 1). Farmers who had *O. smaragdina* in their orchard used significantly fewer insecticides 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 with only 15% in Dong Thap Province.

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, hexithiazox 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 of insecticides used on citrus increased from 16 to 37. On average 1.0 active ingredient was used per farm in 1994 compared with 2.6 different chemicals in 1998. Nearly all products are harmful to *O. smaragdina* and other beneficial organisms.

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

	% farmers using insecticides			
O. smaragdina	1994 (*n*=250)	1998 (*n*=150)	% increase	$\chi 2$
Present	66.1	83.5	17.4	9.94**
Absent	97.1	98.1	1.0	ns
$\chi 2$	16.62***	7.28**		

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

Table 2. Major insecticides used in citrus in 1884 and 1998, in the Mekong Delta

Insecticide	WHO Classification	% 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
Lambada-cyhalothrin	II	–	4.7
Esfenvalerate	II	1.1	8.7
Fenvalerate	II	1.1	3.3
Others			
Imidacloprid	II	–	10.7
Sulphar	IV	–	9.3
Fenvalerate+Dimethoate	–	–	8.0
Propargite	III	–	8.0
Ethofenprox	IV	2.2	7.3
Fenpyroximate	–	–	7.3
Hexithiazox	IV	–	6.0

[a]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.

3.3. Orchard biodiversity and weaver ant abundance

Twenty-six percent of the orchards were under mixed cropping, and had significantly (Pearson $\chi^2=17.51$, $P<0.001$) 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.

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

The 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 with 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 with 13.9 in orchards without. Fungicides were applied as many as 4.8 times per year, compared with 9.8 with or without high ant populations.

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.

3.5. 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 with 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.

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. smaraginda. *Mekong Delta, 1998*

	TM	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

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.

Table 5. Pesticides 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	Ants not abundant	Ants abundant	Ants not abundant
Number of farmers interviewed	42	12	21	57
Insecticides				
No. of insecticides used	1.4 ± 1.4^{a}	2.5 ± 1.7^{b}	2.6 ± 1.8^{b}	4.0 ± 1.7^{c}
No. of insecticides 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 insecticides (%)	21.4	0.0	9.5	1.8
Fungicides				
No. of fungicides used	0.8 ± 1.4^{a}	1.5 ± 1.6^{ab}	2.4 ± 1.9^{bc}	3.0 ± 2.0^{c}
No. of fungicides sprays	1.3 ± 2.1^{a}	1.8 ± 2.1^{a}	4.8 ± 5.3^{a}	9.8 ± 8.0^{b}
Farmers not using fungicides (%)	57.1	33.3	14.3	8.8

Means within rows followed by a different letter are significantly different at the 5% level (LSD, ANOVA).

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

3.6. *Economic assessment related to weaver ant husbandry*

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 t/ha/year. Expenditure data were log (x+1) transformed. Expenditure for insecticides was less when *O. smaragdina* was abundant in sweet orange (df=50; Student's $t=2.29$; $P<0.05$) and in Tieu mandarin (df=67; Student's $t=2.30$; $P<0.05$).

4. Discussion

4.1. *Weaver ant husbandry practices*

The aggressive behaviour of *O. smaragdina* to humans has been an obstacle, and therefore this ant has often been

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

Insecticides	WHO classification[b]	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
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
Sulphar	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
Hexithiazox	IV	0.0	0.0	14.3	14.0

[a]calculated for all orchards except for those five cases where both species were cultivated together, multiple answers occurred.
[b]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 (t/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[a]	152.0[a]	287.4[a]
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]

Means within rows within the same crop followed by a different letter are significantly different at the 5% level (Student's *t*-test).

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.

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 (Van Mele, Cuc and van Huis, unpublished). 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.

4.2. 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).

4.3. 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 survivial 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.

4.4. 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 with 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.

The 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 is very important. In Vietnam, petroleum spray oils (PSOs) 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.

4.5. 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, the 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 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 pesticides should be drawn upon in developing mass media tools and/or farmer training programmes.

4.6. Economic assessment related to weaver ant husbandry

When *O. smaragdina* was abundant, fewer 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, fewer health risks for farmers and consumers, without affecting farmers' income. *O. smaragdina* husbandry should be promoted in both sweet orange and Tieu mandarin production.

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