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Direct and indirect influences of the weaver ant Oecophylla smaragdina on citrus farmers' pest perceptions and management practices in the Mekong Delta, Vietnam

(*Keywords: Oecophylla smaragdina*, citrus leafminer, mites, farmers' perception, decision-making, extension, Vietnam)

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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, high), farmers assessed the incidence, severity and yield loss of fruit caused by major pests. With abundant *O. smaragdina*, sweet orange farmers assessed a lower pest infestation or yield loss for the citrus stinkbug *Rhynchocoris humeralis*, the aphids *Toxoptera aurantii* and *T. citricidus*, the 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, which was rated lower. The number of sprays targeting a particular pest was positively correlated both with pest incidence and severity ratings and was 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 $>30\%$ of all target sprays. Stimulating *O. smaragdina* as a biological control agent in Tieu mandarin will only be successful when citrus leafminer and 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. Farmer participatory training and research that focuses on experiential learning and field observations offers a promising approach to enhance farmers' perceptions of pests, their ecological causalities and non-chemical alternative management options.

1. Introduction

Over the past decade, scientists have increasingly emphasized conservation biological control — the enhancement of 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 may 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; Van Mele, 2000). Farmers' pride in the use of traditional knowledge and practices could be increased if these traditions are validated scientifically (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 with 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 data). Although 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.

2. Materials and methods

In 1998, 132 citrus farmers cultivating sweet orange or Tieu mandarin as their major crop were interviewed in Can Tho and

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Dong Thap provinces, Mekong Delta, Vietnam. Sampling was stratified according to the 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 4 years old. Sweet orange is mainly restricted to Can Tho province and was sampled in Can Tho city, Chau Thanh and Omon districts. 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 for 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 were 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 aimed to get a clear picture of the agro-ecosystem, the farmers' pest risk assessment and the pest management they carried out. A combination of structured and semistructured 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 major pest, pest incidence, pest severity and estimated yield loss were ranked on a three-level scale (low, moderate, 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 (d.f.) = 1, unless otherwise stated. Logistic regressions were conducted to investigate whether ant abundance determined whether specific pesticide products were used. Regression models were routinely calculated starting with all independent variables. At each step, the variable with the highest p was omitted until only significant variables remained in the model (Agresti, 1990). An Odds' ratio (OR) <1 indicated that the product was used by fewer farmers when ants were abundant.

3. Results

3.1. Citrus farmers' profile

O. smaragdina was more abundant in sweet orange (78%) than in Tieu mandarin (27%) orchards. In orchards with abundant ant populations, farmers practised weaver ant husbandry to some extent (Van Mele and Cuc, 2000), partly by avoiding pesticide sprays as much as possible and by avoidance of spraying the nests in the trees. Weaver ant husbandry was generally practised by older sweet orange ($p = 0.08$) and Tieu mandarin ($p < 0.01$) farmers (table 1). About 40% of the farmers were >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 (Pearson $\chi^2 = 20.32$, $p < 0.01$). Trees were older in Tieu mandarin orchards with abundant *O. smaragdina* compared with those without. About 50% of the sweet orange orchards were mixed cropping systems, whereas Tieu mandarin orchards were generally all under monocrop ($\chi^2 = 36.53$, $p < 0.001$). Nearly all orchards were <1 ha.

3.2. 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%) ($\chi^2 = 25.96$, $p < 0.001$). Sweet orange farmers also mentioned more leaf-feeding caterpillars *Papilio* spp. (Lepidoptera: Papilionidae) ($\chi^2 = 9.31$, $p < 0.01$), inflorescence eaters (Lepidoptera: Pyralidae) ($\chi^2 = 12.08$, $p < 0.01$), leafrollers (Lepidoptera: Tortricidae) ($\chi^2 = 27.30$, $p < 0.001$) and branch borers (unidentified) ($\chi^2 = 22.34$, $p < 0.001$). Only six sweet orange growers mentioned citrus psyllids *Diaphorina citri* (Kuwayama) (Homoptera: Psyllidae), vector of the citrus greening disease (CGD). CGD is caused by the bacterium *Liberobacter asiaticum*. Apart from being spread by the psyllid *D. citri*, it is also spread by uncontrolled vegetative propagation. All 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, and on mites and thrips in Dong Thap (Van Mele *et al.*, 2002). Only some Tieu mandarin farmers in Dong Thap reported thrips, *Thrips* sp. and *Scirtothrips* sp. (Thysanoptera). In addition, they also mentioned the citrus red mite *Panonychus citri* (McGregor) (Acarina: Tetranychidae) more frequently ($\chi^2 = 24.11$, $p < 0.01$) than Tieu mandarin or sweet orange farmers in Can Tho did. Mealybugs (Homoptera: Pseudococcidae) ($\chi^2 = 5.76$, $p < 0.05$) and scales (Homoptera: Coccidae, Diaspididae) ($\chi^2 = 3.97$, $p = 0.05$) 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 practising weaver ant husbandry.

The yellow leaf syndrome, mainly indicating 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

*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	
	O. smaragdina abundant (n=42)	*O. smaragdina* not abundant (n=12)	*O. smaragdina* abundant (n=21)	*O. smaragdina* not abundant (n=57)
Age of farmer (years)	54.9 ± 2.2^a	46.8 ± 3.5^a	55.9 ± 2.6^c	46.3 ± 1.5^a
Education (no. of years at 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 of trees (years)	8.9 ± 0.9^a	6.9 ± 1.0^a	9.7 ± 1.2^b	7.0 ± 0.5^a
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]Significant differences at the 5 and 1% levels based on a Student's *t*-test (numerical data) or Pearson χ^2-text (%).

*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*

		Sweet orange		Tieu mandarin	
Insect species	Local name	*O. smaragdina* abundant (n=42)	*O. smaragdina* not abundant (n=12)	*O. smaragdina* abundant (n=21)	*O. smaragdina* 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% levels, respectively (Pearson χ^2-test).

farmers in Dong Thap mentioned this disease. Citrus brown spot, of unknown aetiology, and citrus canker, caused by the bacterium *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 with sweet orange, Tieu mandarin is more susceptible to root rot and therefore is often planted on slightly more elevated soils. Increasingly 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 of honeydew-producing Homoptera, were less cited in Dong Thap province.

3.3. Use of agrochemicals

A complete list of insecticides and fungicides used by citrus farmers in the Mekong Delta was given by Van Mele (2000). The majority of the sweet orange farmers sprayed less than four times a year with insecticides. Tieu mandarin farmers practising weaver ant husbandry sprayed on average seven times a year with insecticides compared with 14 times a year without these ants (Van Mele and Cuc, 2000).

With abundant *O. smaragdina* in their orchard, significantly fewer sweet orange farmers used the organophosphates monocrotophos (OR = 0.26, p = 0.069) and methamidophos (OR = 0.10, p = 0.023), and significantly fewer Tieu mandarin farmers applied methidathion (OR = 0.21, p = 0.007) and fenobucarb (OR = 0.15, p = 0.084). All the insecticides are classified by the World Health Organization as highly hazardous for humans (WHO Class Ib). 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 (WHO Class II). 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 2 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 practising weaver ant husbandry sprayed on average five times a year with fungicides compared with 10 times without these ants (Van Mele and Cuc, 2000). Preliminary experiments with propiconazole (WHO Class II) indicate that sprays did not reduce the number of ants but significantly decreased the ants' foraging and preying activity for at least 2 weeks after application. As the collaborating farmer puts it, 'ants gave the impression of being sick and not hungry'.

On average, sweet orange farmers applied about 300 kg nitrogen, 100 kg phosphorus and 40 kg 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 (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.

3.4. Pest incidence, severity and yield loss assessment

Tieu mandarin growers assessed insect incidence lower (Kendall's τ-b = −0.08, $p=0.079$) and yield loss higher (τ-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.

In both crops, aphid incidence 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. The incidence of leaf-feeding caterpillars was lower with ants. However, reduced yield loss with ants was only recorded for the stinkbug *R. humeralis* and inflorescence eaters. In neither crop was mealybug incidence rated significantly different when *O. smaragdina* was abundant.

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

3.5. 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 practising 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.

4. Discussion

4.1. 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 attributed to its predatory behaviour. The indirect beneficial effect is that most farmers consciously use less pesticide when *O. smaragdina* is present in their orchard, creating a better environment for the survival of other beneficial organisms.

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 (Van Mele and Cuc, 2000). In Tieu mandarin orchards with ants, farmers on average still sprayed insecticides seven times a year, which could affect *O. smaragdina* predation and the activities of other beneficial organisms. Consequently, weaver ant abundance had no influence on Tieu mandarin farmers' perception of pests, with the exception of aphids, which were rated lower with ants.

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 (Van Mele and Cuc, 2000). 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.

*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*

	Sweet orange		Tieu mandarin	
	O. smaragdina abundant (n=42)	*O. smaragdina* not abundant (n=12)	*O. smaragdina* abundant (n=21)	*O. smaragdina* not abundant (n=57)
N (kg ha^{-1})	264.7 ± 28.0[a]	341.2 ± 87.0[a]	316.8 ± 39.5[a]	481.1 ± 41.7[b]
P (kg ha^{-1})	83.5 ± 10.1[a]	130.6 ± 32.5[a]	129.7 ± 17.1[a]	167.4 ± 16.3[a]
K (kg ha^{-1})	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 square-root (x+0.5) transformed before being tested. [a,b,c]Significant differences at the 5 and 1% levels based on Mann–Whitney U-test (kg ha^{-1}), Student's t-test (no.) or Pearson χ^2-test (%).

Table 4. Kendall's τ-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 insect target sprays	*O. smaragdina*
Sweet orange (*C. sinensis*)					
Pest incidence	1.00				
Pest severity	0.55[b]	1.00			
Yield loss	0.37[b]	0.52[b]	1.00		
No. of insect 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 (*C. reticulata)*					
Pest incidence	1.00				
Pest severity	0.34[b]	1.00			
Yield loss	0.30[b]	0.60[b]	1.00		
No. of insect 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 the p=0.05 and 0.01 probability levels.

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

	Incidence			Severity			Yield loss		
Pest	Ants abundant	Ants not abundant	τ-b[1]	Ants abundant	Ants not abundant	τ-b	Ants abundant	Ants not abundant	τ-b
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 τ-b was used to test significance: [a,b]significant difference at the 5 and 1% levels, respectively. A negative sign before τ-b indicates that estimates were lower when ants were abundant.

4.2. Citrus leafminer and stinkbug

Nearly all farmers mentioned the 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 reported in China (Huang and Yang, 1987). *Oecophylla* might also reduce leafminer populations (Barzman, Mills and Cuc, unpublished data). However, in both cropping systems, the 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.

*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*

	Incidence			Severity			Yield loss		
Pest	Ants abundant	Ants not abundant	τ-b[1]	Ants abundant	Ants not abundant	τ-b	Ants abundant	Ants not abundant	τ-b
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[a]	33	80	−0.69[b]	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 τ-b was used to test significance: [a,b]significant difference at the 5 and 1% levels. A negative sign before τ-b indicates that estimates were lower when ants were abundant.

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

	Sweet orange		Tieu mandarin	
Insect species	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 0.01, respectively (Pearson χ^2-test); no letters indicate a non-significant difference.

Chemical control of leafminer has been described as unfeasible 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 reported since the 1980s (CABI, 1998). Enhancing the natural enemies of the citrus leafminer and stimulating synchronous flushing can be integrated with the use of petroleum spray oils (PSOs) (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 on the recommendation of chemical control.

4.3. Mealybugs and scales

Increased problems with scales, mealybugs, mites and thrips are typical for situations where natural enemies have been killed due to an 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 responsive to changes in the pesticide market, being eager to try out new products, irrespective of the higher price (Van Mele and Cuc, 2000). The number of insecticide products used in fruit production doubled from 1994 to 1998, and nearly all had a broad spectrum of activity (Van Mele and Hai, 1999). PSOs 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 the 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.

4.4. Mites

As Tieu mandarin is an economically more profitable crop than sweet orange, the cosmetic appearance is very important (Van Mele and Cuc, 2000). 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 (Van Mele, 2000). Mites are mostly targeted with methidathion, fenpropathrin and several selective acaricides at regular intervals during the rainy season (Van Mele and van Lenteren, 2001). World-wide, 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). 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, personal communication, 2000). After making an inventory of all beneficials, the interactions of these natural enemies with *O. smaragdina* will have to be evaluated as well as the impact of different pesticides on these organisms.

4.5. Extension

So far, weaver ant husbandry has been neglected in most extension activities. The training of young farmers, plant protection and extension staff by both scientists and more experienced older farmers who practice weaver ant husbandry offers good possibilities in a society where Confucianism is a part of daily life (Van Mele *et al.*, 2001). 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 (Van Mele *et al.*, 2002). The challenge is to devise ways to interest staff from the PPD and Extension Service in the promotion of the use of *O. smaragdina* and in reducing pesticide applications. The organization of both a technical support service and farmer groups producing integrated fruit may prove the only way forward to meet export requirements such as maximum residue levels.

Continued international support like the Belgian IPM in fruit project (Van Mele and Coosemans, 1998; Hanssen, 2001), activities supported by CABI Bioscience (Van Mele *et al.*, 2001) and, more recently, the ACIAR-funded project on weaver ants in mango in Vietnam has triggered interest from the government, farmer associations and NGOs working in the Mekong Delta. Currently local government funds are being released to some extent to stimulate weaver ant use. A well-developed and coordinated programme on farmer participatory training and research that focuses on experiential learning and field observations could further enhance farmers' perceptions of pests, their ecological causalities and non-chemical alternative management options (Braun *et al.*, 2000; CABI, 2001; Nelson *et al.*, 2001).

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