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Survey of current crop management practices in a mixed-ricefield landscape, Mekong Delta, Vietnam — potential of habitat manipulation for improved control of citrus leafminer and citrus red mite

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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*). Survey data indicate that these pest problems might be aggravated after farmers have completely destroyed the weed flora in their orchard. 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 could use the weaver ant as an introduction to educating farmers about predatory mites and parasitoids, and should likewise emphasise the importance of beneficial asteraceous weeds such as *Ageratum conyzoides*. Non-crop trees such as *Spondias dulcis*, *Mangifera indica*, *Eucalyptus tereticornis* and *Ceiba pentandra* are commonly known to 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. © 2002 Elsevier Science B.V. All rights reserved.

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1. 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 ricefields have been converted to commercial orchards that are mainly monocultures with Tieu mandarin

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(*C. reticulata*) or longan (*Dimocarpus longan*). Increased land pressure has had a negative effect on landscape vegetational diversity, decreasing the amount of native vegetation and hence undermining the potential for biological control with the weaver ant *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae) in citrus (Van Mele and Cuc, 2000).

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 Letournau, 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, and 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 Letournau, 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).

Because limited 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, personal observation). Initially, farmers had mainly knowledge about those weeds being traditionally used as vegetables or as a source of medicines. Most frequently, 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. Because of 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).

This paper discusses Vietnamese citrus farmers' insect pest and weed management practices in relation to the citrus leafminer *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) and the citrus red mite *Panonychus citri* (Mc Gregor) (Acarina: Tetranychidae). 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.

2. 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 1300 to 1600 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. Table 1 gives the production and orchard characteristics.

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 southeast Asia.

Table 1
Characteristics of surveyed orchards, Mekong Delta, 1998[a]

	Sweet orange	Tieu mandarin
Number of farmers interviewed	57	82
Mean orchard size (ha)	0.7 a	0.6 a
Mean age orchard (years)	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] 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).

3. Results and discussion

3.1. Time profile of major 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 (Fig. 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 (Fig. 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 2 weeks followed by irrigation and fertilization.

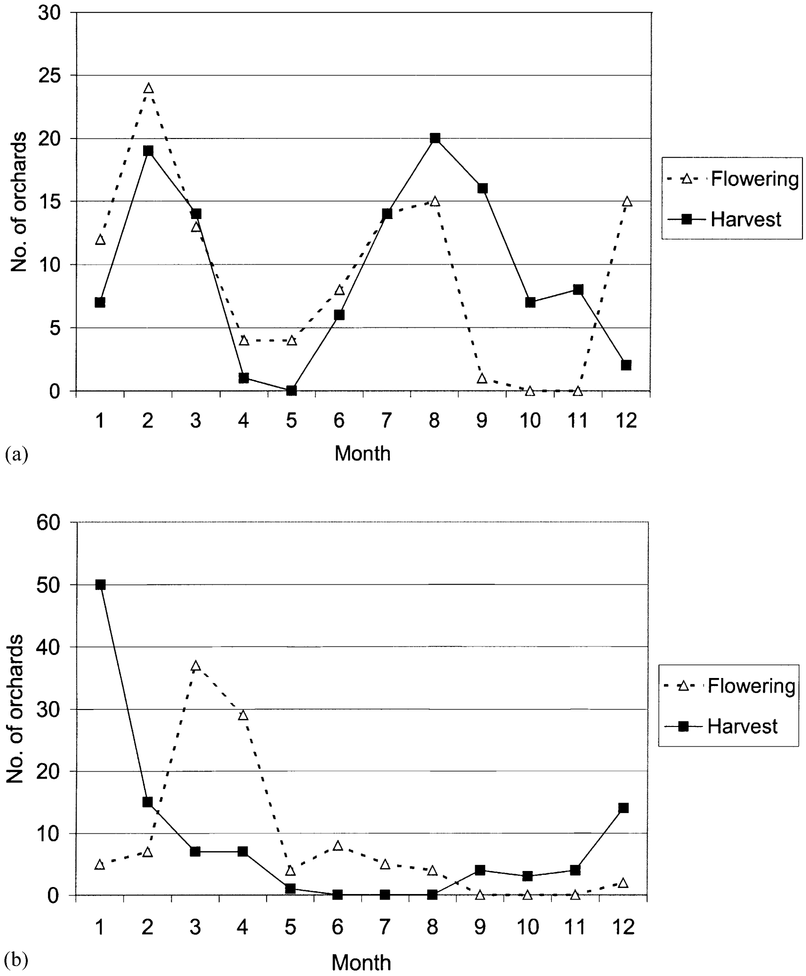

Fig. 1. (a) Flowering and harvest periods of sweet orange (*C. sinensis*) in Can Tho Province, Mekong Delta, Vietnam; (b) flowering and harvest periods of Tieu mandarin (*C. reticulata*), Mekong Delta, Vietnam.

Flowers appear in the period March–April and fruits can be harvested the next year in January (Fig. 1b). This is just prior to the Vietnamese Tet New Year in February, during which mandarins get a high price in the market. CLM was reported to be most problematic during the leaf-flush period in February–March (Fig. 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 (Fig. 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.

3.2. *Target sprays against CLM and mites*

Sweet orange farmers generally sprayed only about three–four times a year (Van Mele and Cuc,

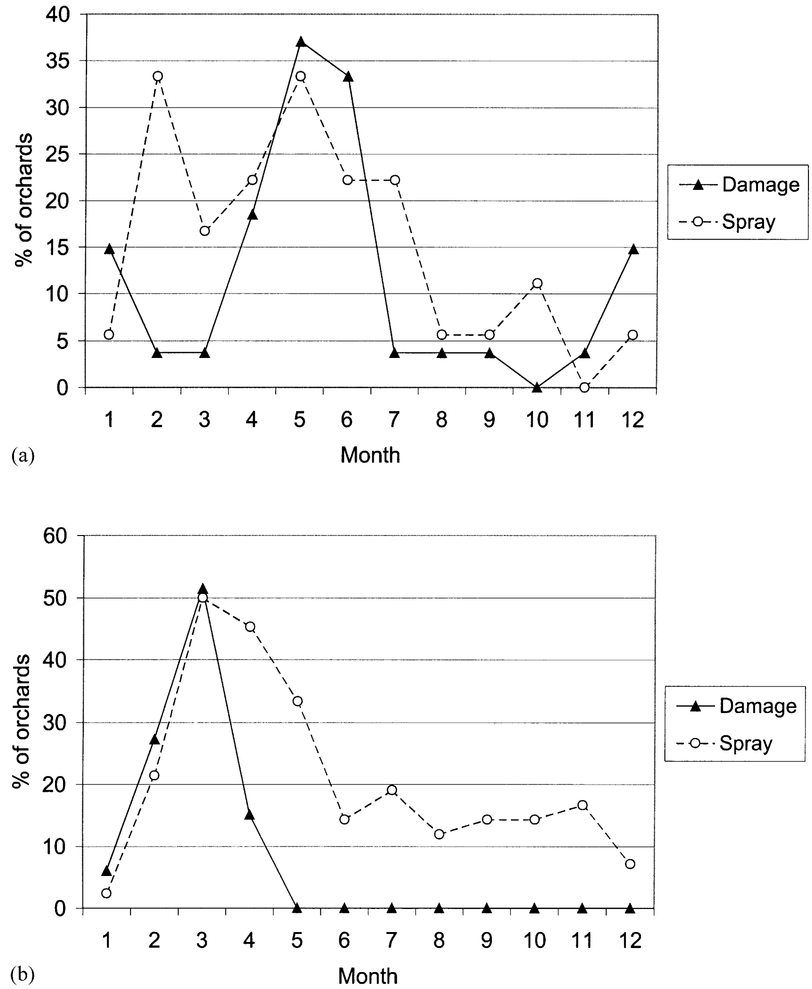

Fig. 2. (a) Peak period of the citrus leafminer (*P. citrella*) according to farmers cultivating sweet orange (*C. sinensis*), and months at which they spray against this target, Mekong Delta, Vietnam; (b) peak period of the citrus leafminer (*P. citrella*) according to farmers cultivating Tieu mandarin (*C. reticulata*), and months at which they spray against this target, Mekong Delta, Vietnam.

2000). CLM and the aphids *Toxoptera aurantii* (Boyer de Fonscolombe) and *T. citricidus* (Kirkaldy) (Homoptera: Aphididae) were the major targets for spraying in sweet orange (Van Mele, 2000), and CLM was mainly targeted from February to July (Fig. 2a). Alpha-cypermethrin and several organophosphorous compounds such as methyl parathion, monocrotophos and methamidophos were most commonly used to target these pests. In the scope of this paper, only data for CLM are presented (Table 2). Surveys conducted in 1994 and 1998 indicated that during this time and probably much longer, more than 50% of the sweet orange farmers applied the organophosphates mentioned above, which are highly hazardous for mammals, fish and natural enemies (Van Mele and Cuc, 2000). Additionally, although the farmers 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 (Van Mele, 2000) and consequently actively targeted this pest, which, together

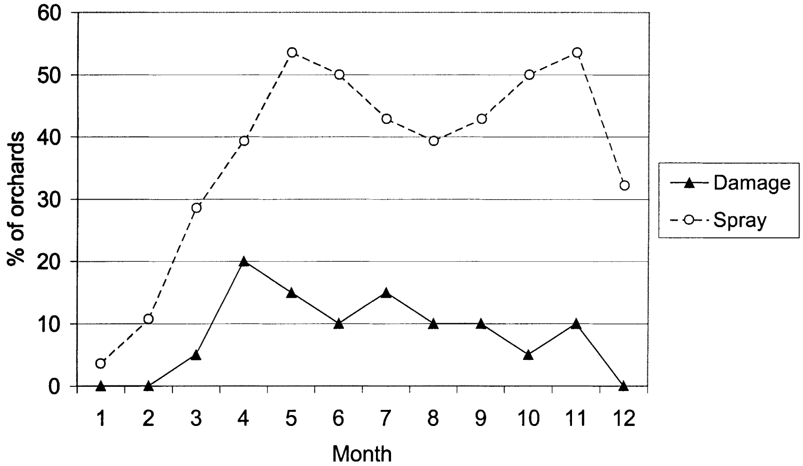

Fig. 3. Peak period of citrus red mite (*Panonychus citri*) according to farmers cultivating Tieu mandarin (*C. reticulata*), and months at which they spray against this target, Mekong Delta, Vietnam.

with the CLM, were among the most important spray targets (Van Mele, 2000). Most of the farmers started spraying against mites from March onwards until December, which is from flowering until harvest (Fig. 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 (Fig. 2b). About 15–20% 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 (Risso) (Homoptera: Pseudo Coccidae). 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). Other systemic broad-spectrum insecticides are commonly used, such as imidacloprid against CLM. Apart from the use of methidathion, mites are 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 (Van Mele and Cuc, 2000) illustrates this. In such intensive cropping systems with high chemical inputs, the role of refugia for beneficial 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.

3.3. 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 being used as a vegetable, also have medicinal applications. For example, *Commelina nudiflora* is used as a diuretic and as a cure for dysentry, among other human diseases. Freshly ground plant material can be applied

Table 2
Number of major target sprays (percentage given between brackets) applied against citrus leafminer *P. citrella* and citrus red mite *Panonychus citri* in sweet orange (SO) and Tieu mandarin (TM), Mekong Delta, 1998

Pesticide	WHO toxicity class[a]	Citrus leafminer		Citrus red mite		Total no.[b]	%
		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	V	0 (0.0)	0 (0.0)	0 (0.0)	11 (3.2)	11	0.7
Others							
Iimidacloprid	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
Fenvalerate+ dimethoate	–	0 (0.0)	30 (9.1)	0 (0.0)	0 (0.0)	37	2.4
Fenpyroximate	–	0 (0.0)	0 (0.0)	0 (0.0)	27 (7.9)	27	1.8
Total no.[c]		94	328	3	342	1576	

[a] Ia: extremely hazardous, Ib: highly hazardous, II: moderately hazardous, III: slightly hazardous, V: unlikely to present acute hazard in normal use, —: unclassified. Source: Anonymous (1999).

[b] Based on all target pests.

[c] Based on total number of target sprays with all the different insecticides including minor ones not included in table.

on the inflammatory areas of bone joints. Leaves of *I. batatas* are used as a laxative. The asteraceous plant *A. conyzoides* is used against coughs and to heal wounds. Besides the direct use by humans, the ground vegetation is also consumed by animals such as chickens or ducks.

Common aquatic ricefield 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 water spinach *Ipomoea aquatica*, is consumed by humans or is offered as green forage to pigs, ducks or chickens. Another aquatic weed *Monochoria vaginalis*, is the most commonly used green forage for ducks, and similarly, 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.

3.4. Farmers' knowledge of the weed flora

Most of the orchards investigated were converted ricefields (Table 1). The weed flora, as reported by farmers, therefore, consisted mainly of common 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,

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[a]	Flowering period (month)	Pollination type[b]	Pollen[c]	Nectar[d]	Remarks	Sources[e]
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
A. conyzoides	Asteraceae	33	6	A	All year	E	+	+	Aromatic, 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	+	–	Nitrophyl, 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

[a] A: annual, P: perennial, s: propagation by seed, v: vegetative propagation.
[b] A: anemophilous, E: entomophilous.
[c] Limited pollen production (–), abundant pollen production (+).
[d] No nectar production (–), nectar production (+).
[e] 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).

1992). Weeds can be categorised as easily observable. Whether a weed is 'important', i.e. '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 down to the species level by farmers. As grasses used as mulch are less important, species-level differentiation was not apparent and farmers used, for instance, just 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 leaved plant' or 'rough leaved 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 before conversion into orchards.

3.5. Scientific considerations about the weed flora

The most frequently noted species are vegetatively propagating perennials (Table 3), that do not produce abundant floral structures (Akobundu, 1987). Pollen production in these plants is, therefore, less than that of annuals. Nearly all weeds reported by farmers were paddy weeds, with many being lowland weeds as defined by Moody (1989). 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 commonly mentioned by farmers growing sweet orange. The last two grasses are intentionally grown by Tieu mandarin farmers as mulch and are, therefore, not considered to be weeds.

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 Letournau, 1982). In Californian citrus, various grasses producing windblown pollen are maintained as an understorey to hasten the seasonal build-up of phytoseiid predatory mites (Bugg and Waddington, 1994). In Australia, Rhodes grass *Chloris gayana* Kunth is commonly allowed to flower in the inter-rows (Smith and Papacek, 1991). Because this grass has a very short life cycle and produces flowers within 3 weeks, year round availability of windblown pollen helps to increase the size of the population of the predatory mite *Amblyseius victoriensis* (Womersley) (Acarina: Phytoseiidae). However, one of the drawbacks with grass-only understorey is a lack of nectar resulting in reduced adult longevity of parasitoids like *Trichogramma* spp. which are widely used for inundative control of lepidopteran pests (Gurr and Wratten, 1999).

Because orchards in the Mekong Delta are often interspersed with ricefields, possible interactions of pests between these two agro-ecosystems should be considered. For example, the grass *Ischaemum rugosum* and the sedge *C. rotundus*, are major hosts of the rice tungro virus (Mallick et al., 1999). The rice weed *L. hexandra* has been observed to harbor high densities of rice leafhoppers, which are major vectors of this virus (Bottenberg et al., 1990). So, to prevent the spread of this virus, grasses should be controlled before panicle emergence to avoid the build-up of grain-sucking rice 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 Letournau, 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 *A. conyzoides* could become an 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 is an important supplementary food source for ladybird beetles (Coleoptera: Coccinellidae), and lacewings (Neuroptera: Chrysopidae) seem to prefer composite flowers as a source of 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 Letournau, 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 ground cover in orchards, 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). In addition, weeds can often provide other essential requirements for predatory mites, for example, the white down covering the plant of A. *conyzoides*, provides an ideal oviposition site for predatory mites (Olkowski and Zhang, 1998). Provided predatory mites are present in the crop early in the season, control of mite pests is possible (Flint, 1991; Smith et al., 1997). It appears that the use of broad-spectrum insecticides destroys the natural balance between predators and prey, thus triggering the outbreak of mite pests. As citrus farmers in the Mekong Delta do not have any knowledge about predatory mites and parasitoids, this cycle is likely to be common. However, they are aware of predation by the weaver ant *O. smaragdina*, and the benefits it provides (Van Mele and Cuc, 2000). Weaver ant predation could be used as a starting point to learn farmers about the existence and role of predatory mites. Because this generalist predator is compatible with most other beneficial organisms that control pests such as scales, aphids, mealybugs and mites (Huang and Yang, 1987), the weaver ant could be used as an introduction to educating farmers about the existence and role of predatory mites and parasitoids. IPM training programmes should likewise emphasise the importance of beneficial asteraceous weeds such as *A. conyzoides, Blumea glandulosa, Vernonia cinerata* and *Eclipta prostrata*.

3.6. 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 2 to 3 months in older orchards. Mulching was the second most important weed management technique, being practised in about 70% of all citrus orchards. Herbicides were used by 20% of the sweet orange farmers, and by 30% of the Tieu mandarin farmers, the latter also having the highest use of insecticides and fungicides (Van Mele and Hai, 1999; Van Mele and Cuc, 2000).

Farmers applying herbicides sprayed twice a year on an average, once in the beginning and once at the end of the rainy season. More than 80% of the farmers applying herbicides used only one product against both annuals and perennials, namely the non-selective, translocated herbicide glyphosate. Less than 20% of the farmers applied paraquat against annuals and

Table 4
Weed management practices of fruit farmers, Mekong Delta, 1998[a]

	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 number of sprays	2.0 a	2.2 a
Mean number of products	1.1 a	1.2 a

[a] 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).

2,4-D against both annual and perennial broadleafed weeds. Because herbicides are applied in the rainy season, run-off to the canals in between the planting beds is highly likely. The toxicity of herbicides to fish has been documented, 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, but global effects of pollution on water quality should be considered as this will become more problematic in the near future. Glyphosate increases colonization and infection of *Fusarium solani* in the root system of peas (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., which are antagonistic bacteria of soil-borne diseases (Thu et al., 1999). 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 farmers must use herbicides, the best option would be to apply mixtures of different herbicides, preferably applied in rotation (Kazuyoshi and Suzuki, 1981; Akobundu, 1987). Additionally, products that are more selective against grassy weeds and not harmful to asteraceous weeds such as fenoxaprop ('Whip's') and thiobencarb ('Saturn') are recommended in preference to currently used products (Ampong-Nyarko and De Datta, 1991).

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 moving 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 fast growing grasses like *Oryza rufipogon, Ischaemum indicum* and *Sacciolepis interrupta*. 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 in Thai orchards to reduce the abundance of annual weeds, while geese are often used to graze *C. rotundus* (Suwanarak and Supasilapa, 1990). However, in the Mekong Delta, rice straw and husks were used only in some cases, despite their great abundance and availability in the region. Many competing applications of these natural resources make them more difficult to purchase (Van Mele, 1998a). In a pineapple intercrop under coconut in Sri Lanka, mulching with coconut coir dust significantly suppressed *A. 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, or to compost the weeds first before applying them around the tree base. An added advantage of the latter proposal is that the effectiveness of beneficial fungi, such as *Trichoderma* spp., which suppresses soilborne diseases, is increased in aged compost (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 1 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 are incorporated, increasing soil stability. In addition, abundant nutrients are added 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 by destroying 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 may deprive 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 a ground cover because 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 is released before the stigmas of the same flower become receptive. Later on, pollen is forced upwards by the emerging stigma, making all the pollen 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, phytophagous mites were reported to be a problem from March onwards (Fig. 3). By cleaning the canals in February–March, it is very well possible that the available predatory mites are suppressed because of food deprivation, allowing an outbreak in phytophagous mites.

Because small modifications of farmer practices have better chance of being adopted by farmers (Matteson et al., 1984), some minor changes that could make the practice of canal clearing a more compatible and even beneficial practice within an IPM programme are suggested here. 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 practised 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 practised 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.

3.7. 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 (Van Mele, 2000). Farmers taking care of these ants apply significantly less insecticides and fungicides (Van Mele and Cuc, 2000). 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 a monoculture not mixed with other trees with only a ground cover. This implies that after each weeding event, Tieu mandarin is converted into a monocrop *sensu stricto*. The non-crop trees in sweet orange, therefore, not only give the agro-ecosystem a greater structural diversity, but also a better continuity of food supply over time. Some trees are commonly colonized by *O. smaragdina*, including *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, and *Eucalyptus tereticornis* (Myrtaceae) and *Ceiba pentandra* (Bombacaceae), which offer good potential for weaver ant husbandry among some other sociological and economic functions (Van Mele, 1999; Van Mele and Cuc, 2000). 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), hence those non-crop trees colonized by ants should be studied for their temporal contribution as a food resource, or as alternate host plants for pests. Such trees should also be investigated for their potential to provide food and shelter for predatory mites and other beneficial organisms, as has been demonstrated in other crops. 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 *E. torelliana* F. Muell. acted as reservoirs of the predatory mite *A. victoriensis* for nearby blocks of citrus in Australia (Smith and Papacek, 1991). As phytoseiids use air currents as a major means of dispersal, they can easily enter a crop from such windbreaks. 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.

Further study is recommended into 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.

4. Conclusion

The use of highly toxic pesticides in orchards in the Mekong Delta deserves special attention because it affects human health, fish production, and natural enemies among other aspects of environmental degradation. Severe outbreaks of the citrus leafminer and the citrus red mite might be attributed to a strong reduction of their natural enemies. The conservation of these beneficial organisms through habitat manipulation has great potential in the diverse 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 that weeds may play in maintaining populations of beneficials. Farmers should be trained to conserve asteraceous weeds like *A. conyzoides* as an important pollen source for predatory mites. Because 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.

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