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MANAGEMENT OF SELECTED INSECT PESTS WITH PEST-ATTRACTIVE PLANTS IN ORGANIC TANGERINE FARMING SYSTEMS IN NORTHERN THAILAND

Chomchuan Boonrahong and Senaratne L. Ranamukhaarachchi*

Asian Institute of Technology, Thailand

Abstract

Tangerine is a cash crop in Thailand which is heavily vulnerable to insect pests. Heavy use of pesticides has severely affected environment and people's health. This study was conducted to assess the biological pest management potential using pest attractive plant species to reduce the use of highly toxic pesticides and to improve the quality of the product and environment health.

Sixteen suspected weed species were allowed to grow with tangerine and tested their pest attractiveness for four key insect pests for 12 weeks. From this study, three weeds [viz. goat weed (Ageratum conyzoides), Siam weed (*Chromolaena odorata*), and buffalo grass (*Paspalum conjugatum*)] were identified for further studies and tested together with cowpea (*Vigna unguiculata*), rice (*Oryza sativa*) and chilly pepper (*Capsicum frutescens*) based on farmers' information in an organically grown tangerine farm.

All plant species tested attracted citrus leafminers and citrus whiteflies as tangerine pests, and among the natural enemies, ladybird beetle and weaver ants. Asian citrus psyllids were attracted on buffalo grass, rice and chilly peppers, while black citrus aphids were attracted on Siam weed and chilly peppers only. The two natural enemies namely, green lacewings and tropical orb weaver spiders were attracted by Siam weed, buffalo grass and rice, which together with chilly peppers attracted tropical orb weaver. The Asian citrus psyllids and citrus whitefly damage on tangerine associated with chilly peppers was minor-moderate, minor with Siam weed, buffalo grass and rice, but not observed on tangerine associated with goat weed and cowpea. Black citrus aphid damage was minor on tangerine associated with all plants, except cowpea. Citrus leafminer damage was between minor-moderate in tangerine associated with Siam weed and cowpea, and above moderate-heavy with rest of the plant species. These results show that pest attraction varies with plant species and by selecting plant species in a mixed stand with cowpea and chilly peppers and by leaving these weeds can help managed tangerine pests and minimize use of toxic pesticides.

Keywords: Tangerine, insect pests, natural enemies, pest attractive plants

Introduction

Tangerine is an economic crop grown mainly at the central and northern regions in Thailand. It is largely grown as a sole crop, and managed with a combination of manual and mechanical methods (Bedford *et al.*, 1998). Due to its perennial nature combined with extensive management the tangerine cultivations provide a fine habitat for many insect pests (Bedford *et al.*, 1998). The economically important pests in tangerine include citrus psyllid (*Diaphorina citri*), black citrus aphid (*Toxoptera aurantii*), golden green weevil (*Hypomeces squamosus*), thrips (*Scitrotrips sp.*), citrus red mites (*Panonychus citri*), citrus leafminer (*Phllocnistis citrella*), oriental fruit fly (*Bactocera dorsalis*), spherical mealybug (*Planococcus citri*), citrus whitefly (*Dialeurodes citri*), and hard scales (*Chrysomphlus aonidum*) (Morakot and Nunta, 1996; Joemsiri and Pannim, 2000). The nature of pest damage on tangerine varies with the species of insects due to their feeding habits (Chapman, 1998). Heavy infestation of leaf eating species affect the plant growth and can rapidly kill a young citrus tree (Anon, 2009), while piercing and sucking types damage both leaves and fruits causing heavy economic losses (Broughtom, 2007).

The management of tangerine pests is mainly reliance on chemical pesticides due to the large extent of cultivation (Paradornuwat *et al.*, 1999; Yimsaman, 2004). The common insecticides used are dimethoate, cypermethrin, methamidophos, flufenoxuron, methomyl, monochrotophos, imidacloprid, and carbosulfan, which lead to contamination of the environment and affects human health (Jungbluth, 2000). Tangerine farmers have experienced symptoms of acute pesticide poisoning such as dizziness, muscular pain, headache, nausea and difficulty in breathing (Khuankaew, 1995).

* Corresponding Author, *Email*: ranamuka@gmail.com

Sinhaseni (1994) reported that almost 50% tangerine growers in Pathumthani province suffered from pesticide poisoning. Paradornuwat *et al.* (1999) noted that the knowledge of insects pest species and natural enemies would be required if the pest management to be deviated towards environmentally friendly activity.

Increasing the diversity of plant species is one of the practical means of reducing the impact of pests. The intercropping and trap cropping with attractant plants enhance the plant diversity and reduce the pest incidence (Stoll, 2000). According to Van Emden and Williams (1974) the components of diversity is more important than vegetation diversity for optimal biological control of insect pests in crops. Weeds also influence the diversity and abundance of insect herbivores and associated natural enemies in crop systems (Altieri, 1994). The destroying of weed flora from the orchards and canal areas severely enhanced the incidence of citrus leaf miner and the citrus red mite in sweet orange (*Citrus sinensis*) and Tieu mandarin (*C. reticulata*) in the Mekong Delta, Vietnam (Mele and van Lenteren, 2002).

Certain weeds from the family Umbelliferae, Leguminosae and Compositae play an important ecological role by harboring beneficial arthropods that aid in suppressing insect pest populations (Altieri *et al*., 1977; Altieri and Whitcommb, 1979 and 1980). Furthermore, Altieri and Schmidt (1985) reported that orchards with rich floral undergrowth exhibited a lower incidence of insect pests than clean-weeded orchards, which was due mainly to increased abundance of predators and parasitoids. The use of herbicides in intensive agriculture has reduced floral diversity, resulting in reduction of the number of arthropods by half and their biomass by two-thirds (Van Emden and Williams, 1974).

Some weeds such as goat weed (*Ageratum conyzoides),* Siam weed (*Chromolaena odorata* and buffalo grass (*Paspalum conjugatum*) attract some insects of the order of Orthoptera, Hemiptera, Thysanoptera, Diptera, Lepidoptera and Coleoptera. *Mesochorus spp.* from the Ichneumonidae family (i.e. parasitoids, wasps) must feed on nectar for their egg maturation (Waterhouse, 1994; Van Emden, 1965). Similarly, Leius (1967) reported that carbohydrates from the nectar of certain Umbelliferae are essential in normal fecundity and longevity of three Ichneumonidae spp. *Murraya paniculata* (L.), an ornamental plant attracts citrus psyllids, the vector of the citrus greening disease (Aubert, 1990). Similarly, Napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum vulgare sudanese*) attract natural enemies of maize stem borer, the parasitic wasp (*Cotesia sesamiae*) (Khan *et al*., 1997). On the other hand, molasses grass (*Melinis minutifolia*) repelled ticks, and silverleaf (*Desmodium* spp.) suppressed the parasitic weed Striga (Khan *et al.,* 1997).

The above information indicated that crop pests could be managed by modifying the plant diversity with increasing pest attractive plants or even retaining effective weeds and maintaining beneficial rich floral undergrowth in croplands. The findings will help make use of effective plant species instead of highly toxic pesticides in conventional pest management, reduce health risks and maintain environment health associated with tangerine cultivation. However, there was no research in such direction in tangerine plantations. Therefore, the objective of this study was to identify and evaluate plant species that could attract or repel key insect pests in tangerine and attract their natural enemies.

Materials and Methods

This study was conducted during June 2006 to May 2008 in the Fang Watershed, Chiang Mai, Thailand (latitude 19-35-0 N - 20-5-0 N, longitude 99-5-0 E - 99-30-0 E and altitude 465 m above mean sea level). In the experimental area of Fang watershed, annual temperature varies from 8.9^{o} to 36.1^{o}C and relative humidity from 18 to 100 %. The rainfall in the study year of 2006 was 1,506 mm (Anon, 2010a). Soil is friable, well-drained with pH of 4.5-5.5 and CEC of 1.45-6.70 meq/100g (Anon, 1998).

The study included two parts. The first part was a field observation cum survey-based study to select plant species that attract or repel selected insect pests of tangerine and their natural enemies. The second part evaluated the suitability of selected plants from the first field study for insect pest behavior and their impact on tangerine.

An organically-managed tangerine farm was used for the study. This was due to the fact that organic fruit production is an area of popular demand in Thailand to avoid high pesticide residue in tangerine and its impact on export and foreign exchange earnings and to ensure that there was no disruption of both insect pests and their natural enemies and their populations by synthetic pesticides. The details of the study are described below:

The Experiment 1: Identification of plant species associating with tangerine capable of repellence and/or pest attraction of economically important insect pests and their natural enemies-

This study was conducted in an organically managed tangerine farm in Maenawang sub-district, Mae Ai district, Chiang Mai province, Thailand (Longitude 99-5-0 E - 99-30-0 E and latitude 19-35-0 N - 20-5-0 N and altitude at 465 m AMSL), during June

06, 2006 to August 27, 2006. Tangerine trees of five spacing of 4 m x 4 m, without any vacancies in the field were used for the study. The crop was rainfed and had been managed with weeding at bi-weekly intervals using motor-driven grass-cutter, applied with compost and pruned excessive branches.

Initially the field was fully examined for profusely growing weeds associating with tangerine trees, and the trees associated with such weeds were marked, the weeds were later identified to species levels using weed identification manuals, keys and personal experience. From these plant species, most common and abundant once were selected for the study. In the selection, the species with a continuous patch covering at least 20% of the area around the tangerine tree and when there were at least three citrus trees available with that weed were chosen. Accordingly, 16 weed species were used in the first study for monitoring pest and natural enemy.

The selected weed species were allowed to grow for three weeks before beginning to monitor insect pests and natural enemies. One square meter area of each selected weed growing under or overlapping with the tangerine tree canopy was demarcated using four wooden pegs and twine to record insect pests and their natural enemies. Prior to commencing insect counts, there was a familiarization exercise for tangerine pests and their natural enemies, in which insect pests on citrus and other natural enemies were collected from the trees and weeds growing outside the demarcated plots. The insects were identified using insect identification keys (Malaipun, 1995; Morakot and Nunta, 1996; Jamornmarn, 1997; Namrungsri *et al.*, 2005) and plant pest manuals (Waterhouse, 1994). Especially those unfamiliar natural enemies were identified with the assistance of a person specialized in entomology and plant protection as well as entomologists at Mae Jo University, Chiang Mai.

In the experiment, two places were targeted for pest monitoring: a) already demarcated area of the weed patch (one square meter), and b) randomly selected branches of each tangerine tree up to one-meter area of the canopy perimeter, facing the demarcated weed patch. Monitoring of insect pests and natural enemies commenced on the second month after allowing the weeds to grow freely with no interruption, and continued for ten consecutive weeks on a weekly basis. Insect collection was begun from 06:00 to 09:00 a.m. and 4:30 to 6:30 p.m. on designated sampling dates. The collection, identification and recording were made by collecting insects using a net for flying insects and predators and parasitoids, and direct counting for aphids and observing of affected leaves with tunnels for leafminers. The insects were examined with the help of a magnifying glass for small pests such as thrips, mites, aphid and leafminer. The insects collected were released to the same area after completing the counting and recording.

The study concentrated on four key pests of tangerine as their damage affects the plant health and quality and quantity of tangerine fruits produced, and promotes uncontrolled application of pesticides affecting the environment health. These pests were Asian citrus psyllid, black citrus aphid, citrus leafminer and citrus whitefly. In addition, important natural enemies of the same four pests, namely ladybird beetle, green lacewing, tropical orb weaver spider and weaver ant (*Oecophylla smaragdina*) were monitored on both tangerine and selected weeds.

During the ten week period, selected weeds were maintained by removing other weed species that emerged in the patch. There was no pesticide applied, no irrigation adopted, and no pruning of tangerine branches made.

The data were subjected to descriptive analysis. Graphical presentation was made to understand population variations of both insects and natural enemies. Three weed species were chosen based on the attraction of insect pests and natural enemies for the next study for further evaluation.

Experiment 2: Evaluation of selected plant species for repellence/attraction of tangerine pests and natural enemies

This experiment was conducted to re-evaluate the three weed species screened from the field study together with three other plants species nominated by farmers for pest attraction based on their long experience and to determine their influence on pest damage on tangerine. The farmers' choice plants were cowpea (*Vigna unguiculata*), chilly pepper (*Capsicum frutescens* L) and rice (*Oryza sativa* L). There were six plant species associated with tangerine as treatments in the experiment, which were replicated four times. A single tangerine tree was considered as an experimental unit. The experiment was conducted in complete randomized design with four replicates. There were 24 tangerine trees selected, and treatments (three weeds and three plants nominated by the farmers) were randomly assigned among these trees.

In the preparation of each tangerine tree and weed/plant association for the experiment, the selected plant species were multiplied in sufficient numbers in pots and maintained for two weeks. The six weeds species were transplanted underneath and around the trees. Plants were watered every day for two weeks to

facilitate their establishment. Once the plants were in active growth stages - determined by growth habit and greenness of the foliage together with 75% ground cover establishment – pest and natural enemy counting was commenced. Pests and natural enemies were examined at two one-square meter areas of weeds/plants marked on opposite sides under each tangerine tree, and on branches at lower part of the tangerine tree.

Extent of pest damage was estimated using different ranking methods for specific insects. Number of leaves curled (per shoot) was counted and recorded for black citrus aphid due to its piercing-sucking mode of feeding (Broughtom, 2007). Number of leaves with shallow tunnels was recorded to judge citrus leafminer damage (Anon, 2008). Number of shoots with sooty mold fungus was used for estimating Asian citrus psyllid and whitefly damage (Fasulo, 2007). Citrus whiteflies consume a large volume of sap using piercing and sucking mouth parts, and further injury caused by sooty mold fungus which grows over fruit and foliage on honeydew excreted by the citrus whitefly (Majumdar, 2009). High populations of Asian citrus psyllid nymphs and adults also cause significant sap removal and permanent deformation of leaves and shoots, and honeydew produced by nymphs and adults allows growth of sooty mold that coats leaves and further reduces photosynthesis in plants (Majumdar, 2009). Pest counting was done in the morning hours from 6:00 to 9:00 a.m. and 4:30 to 6:30 p.m., while pest damages were estimated during 11:00 a.m. to 3:30 p.m. The evaluation of pest repellence/attraction was carried out on a weekly basis for ten consecutive weeks during October 31, 2007-January 17, 2008 period. Insect counts were analyzed using descriptive statistics, and categorical data analysis procedure. Graphical presentations were made to illustrate population variation during the study period.

Results

Experiment 1: Distribution of selected insect pests

The insect pests and natural enemies observed on 16 weed species are shown in Table 1. Eight weed species were observed to having Asian citrus psyllid, and its number ranged from one in wild spider flower (*Cleome gynandra*) to 12 in Siam weed. Eight weed species did not have Asian citrus psyllid during the 10-week period of observation. Black citrus aphids were found only on four weed species namely Siam weed, crowfoot grass, buffalo grass and goat weed. Siam weed had the highest number of black citrus aphid (352). Citrus leaf minor was found on nine out of sixteen weed species, and the highest number was on bitter cucumber (*Mormordica charantia*) while the lowest was on American weed (*Synedrella nodiflora*) (only 2/weed). Citrus white flies were observed on seven out of 16 weed species, and its population was high on green kyllinga (*Kyllinga brevifolia*), Siam weed, and buffalo grass.

Among the natural enemies both ladybird beetle and weaver ants were abundant in the organic tangerine farm. Green lacewings were very few and found only on six weed species, and tropical orb weaver spider on six weed species. Weaver ant was common on 12 weed species, while ladybird beetle was found on ten weed species. A few weed species did not have any of the selected pest and natural enemies (Table 1).

The presence of selected insect pests on specific weeds indicates that a) such pests may have varying degree of affinity to some plant species, b) specific weeds have strong attraction for such insect pests against other plants and /or c) there would be a potential for reducing insect pest incidence by selecting suitable pest attractive plants species in tangerine. The pests were absent in a few weed species such as goose grass (*Eleusine indica*), Maxican fireplant (*Euphorbia heterophylla*), snake weed (*Euphorbia hirta*) and crab grass (*Digitaria ciliaris*). Asian citrus psyllid, black citrus aphid and citrus whitefly were not observed on benghal dayflower (*Commelina benghalensis*), but citrus leafminer were present. Asian citrus psyllid and black citrus aphid were absent on spreading dayflower (*Commelina diffusa*), while black citrus aphid and citrus leafminer were absent on wild spider flower.

Similarly, some natural enemies were present on some weed species and not observed on other weeds. The presence or absence of natural enemies indicates the availability or level of abundance of their prey. The absence of natural enemies could be a result of a) absence of insect pests (prey) on specific weeds, b) total destruction of insect pests by natural enemies in the location, c) total insect pest repellence by weed species, d) absence of insect pests at all in the plant patch selection, and e) complete attraction of the insect pests by the associated tangerine trees. On the other hand, the presence of some insect pests may give the message of a) inadequate number of natural enemies in a high pest infested site, and b) absence of natural enemies. It would be hard to reach a realistic conclusion based on the presence or absence of insect pests and/or natural enemies due to the frequent mobility of insects.

Three weed species Siam weed, goat weed, and buffalo grass had a greater attraction of selected pests and their enemies during the experiment, and hence were chosen for the second experiment.

Table 1. Plant species examined for pest repellence and pest attraction, and mean daily pest and natural enemy populations observed at one day per week for 10-week period.

Name of Weed	Pest, no./m^2				Predator, no./m^2			
	Psyllid	Aphid	Leaf miner	White fly	Lady bird beetle	Green lace wing	Tropical orb weaver	Weaver ant
Siam weed *(Chromolaena odorata)*	12±25	352±241	7±11	10±5	20±11	5±3	8±2	39±28
Green kyllinga (*Kyllinga brevifolia*)	0	0	0	54±82	0	2±1	5±3	0
Goose grass *(Eleusine indica)*	0	0	0	0	0	0	2±1	5±3
Spreading dayflower *(Commelina diffusa)*	0	0	6±4	2±1	0	0	0	6±4
Maxican fireplant *(Euphobia heterophylla)*	0	0	0	0	2±1	0	1±1	2±1
Goat weed *(Ageratum conyzoides)*	3±2	33±26	5±3.1	0	10±5	6±4	5±3	3±1
Benghal dayflower *(Commelina benghalensis)*	0	0	3±1.6	0	10±5	0	0	4±3
Cogon grass *(Imperata cylindrica)*	3±1	0	0	5±3	12±24	5±3	0	8±2
Snake weed *(Euphorbia hirta)*	0	0	0	0	0	0	0	4±3
Crowfoot grass *(Dactyloctenium aegyptium)*	6±4	2±2	5±3	0	7±11	4±3	0	5±12
American weed *(Synedrella nodiflora)*	4±3	0	2±1	2±20	5±3	0	0	4±3
Buffalo grass *(Paspalum conjugatum)*	7±11	4±3	8±2	18±8	10±5	3±1	1±1	11±8
Crab grass *(Digitaria ciliaris)*	0	0	0	0	3±1	0	0	4±3
Wild spider flower *(Cleome gynandra)*	1±1	0	0	8±2	0	0	0	0
Bitter cucumber *(Mormodica charantia)*	0	0	20±11	0	4±3	0	0	0
Ivy gourd *(Coccinia grandis)*	3±1	0	10±5	0	0	0	0	0

Experiment 2: Insect pest populations on selected plant species

Asian citrus psyllid: Asian citrus psyllid population behaved similarly on all tangerine trees associated with selected plant (Figure 1Aa). However, Asian citrus psyllid populations had varying degree of infestation on tangerine trees associated with all plants during the 12-week period. Rice had its peak infestation in the first week and also in the 11th week. Cowpea had a minor peak in the 10th week and a major peak in the 11th week and then declined. Goat weed too had a minor peak during the 5th week and a higher peak in the 9th week, buffalo grass having one major peak between 5th and 6th week, chilly pepper had a peak infestation in the second week and then in the 6th week. Tangerine associated with Siam weed had Asian citrus psyllid populations below 5 insects per tree during the 12 weeks period.

The number of Asian citrus psyllids on associated plants species was around 2-7 during the study period, except in the 5th and 7th weeks in rice, chilly pepper, buffalo grass, and Siam weed (Figure 1Ab). No other plant species had Asian citrus psyllids during any other days.

Black Citrus Aphid: Black Citrus Aphid population on tangerine fluctuated during the observation period (Figure 1Ba). Black Citrus Aphid was not found on tangerine at the beginning, but later its population increased up to 250 insects per tree. However, tangerine associated with goat weed had 1,275 insects during 7th and 8th weeks and 325 in the 10th week. The lowest black citrus aphid population on tangerine (37) was found in cowpea association.

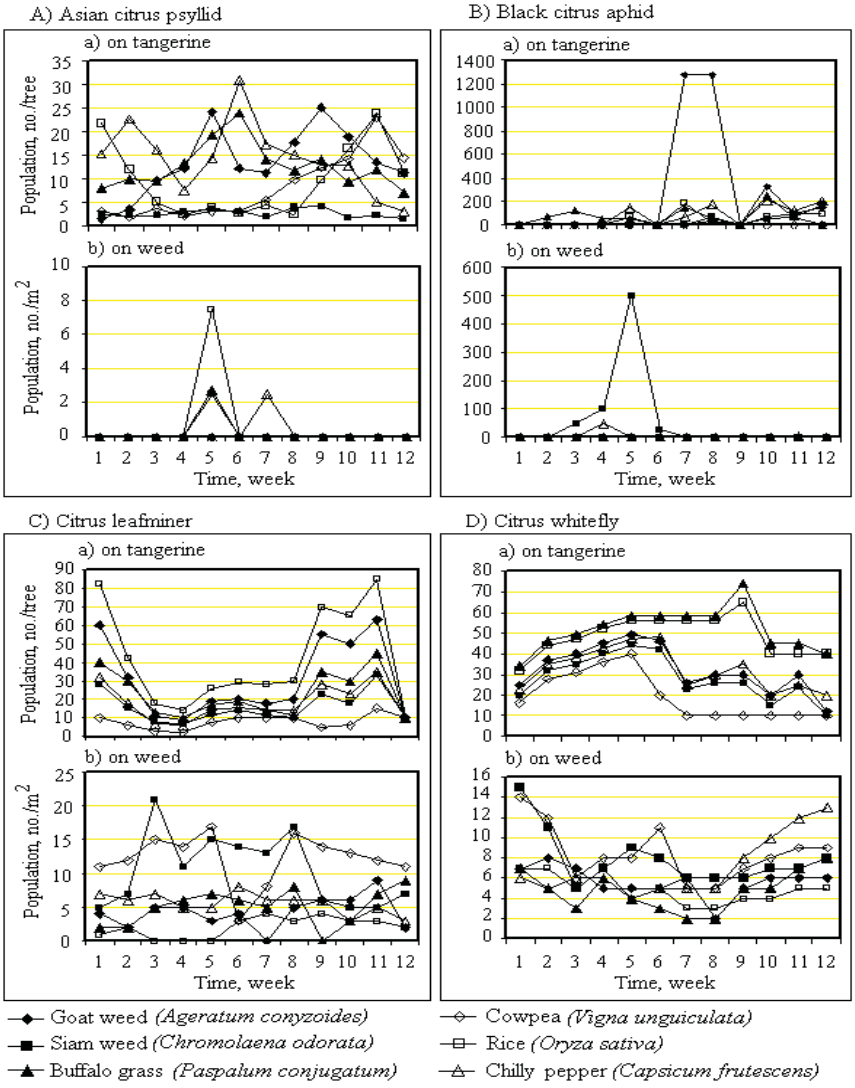
Among associated plant species, only Siam weed had black citrus aphids in the 3-6 weeks with a peak of 503 in the 5th week (Figure 1Bb). The black citrus aphid population began to increase in the 3rd week with 50 /m^2 and reached 503 and decreased to 25 in the 6th week. There were 53 black citrus aphids on chilly pepper in the 4th week. Other plant species showed no attraction for black citrus aphids. It also showed that both Siam weed and chilly pepper have some regulatory effects on black citrus aphid in tangerine.

Citrus leafminer: Citrus leafminer population on tangerine trees associated with all plant species behaved in the same pattern during the study period, except in the number per tree (Figure 1Ca.). Citrus leafminer population on tangerine was initially high, and decreased towards 3rd week and maintained low until 8th week, then exploded in the next 3 weeks, and finally declining in the 12th week. The citrus leafminer population was highest on tangerine associated with rice and declined in the order of goat weed, buffalo grass, chilly peppers, Siam weed and cowpea.

This shows that there is a regulation of citrus leafminer population by associated plant species, rice

having the lowest attraction and cowpea with the highest (Figure 1Cb). Both Siam weed and cowpea

Figure 1. Population of selected citrus pests on tangerine and associated plant species in organic tangerine



had the highest number of citrus leafminers among associated plants, chilly pepper, buffalo grass and goat weed being moderate and the rest of the plant species having low populations. As per populations of citrus leafminer on tangerine and selected plant species, citrus leafminer appeared to have been regulated and also capable of regulation by using the associated plant species.

Citrus whitefly: Citrus whiteflies on tangerine behaved similarly as citrus leafminer (Figure 1Da). The trend of population dynamics showed its variation, started with a low population which gradually increased until 5th week. In tangerine associated with buffalo grass had the highest number of citrus white flies which increased until 9th week and declined thereafter. Similar trend but slightly lower population was observed in rice association. Tangerine associated with goat weed, Siam weed and chilly pepper had approximately similar populations of citrus whiteflies. On the other hand, cowpea association had the lowest citrus whitefly population on tangerine trees.

All selected plant species had citrus whitefly populations ranging from 6-15 at the beginning of the observation period and fluctuations resulted as the time continued. Based on the total citrus whiteflies found on each association of tangerine and weeds, there was

still a reduction of citrus whitefly population on tangerine due to associate weeds. Both goat weed and chilly pepper showed the opposite trends of citrus whitefly populations on weeds as compared to that on associated tangerine trees. In addition, increasing citrus whitefly population on cowpea after the sixth week showed its pest attractive effect. However, the reduction of citrus whitefly population on both tangerine and associated plant species could also be attributed to aging effects of insects and maturity of plants.

Populations of Natural enemies

Ladybird beetle: Ladybird beetle population on tangerine was prominent on goat weed and chilly pepper at the first week, but decreased drastically to none during the remaining period (Figure 2Aa). Ladybird beetle was not found on Tangerine associated with all other plant species during any of the remaining sampling dates after 2nd week.

Ladybird beetle populations on associated plant species showed a heavy diversity during the study period (Figure 2Ab). The highest ladybird beetle population was in the goat weed followed by buffalo grass with the same trend. In addition, there was often a fluctuation of ladybird beetle population on associated plant species. Ladybird beetle being an active feeder of many insects such as aphids, white flies, mites, thrips, and other small insects, its ability to rapidly increasing the population on associated plant species is expected in effective biological pest management (Weeden *et al.*, 2007). In addition, although many ladybird beetles were not found on tangerine, its frequent association with the plant species growing underneath tangerine indicates the frequent availability of prey. In this aspects all plant species used appeared to have different types of insects whether they belonged to pests or not, that could provide prey for ladybird beetle and keeping its population within the crop.

Green lacewing: Green lacewing population was very low in the tangerine farm with the mean number ranging from 0 to the highest of 5 per tangerine tree (Figure 2Ba). There was no comparison made in their populations with other tangerine habitats. The number of green lacewings increased until 4th week and then declined. There was green lacewing found on tangerine associated with buffalo grass and chilly pepper, but not on the associated weeds or crop plants during the period of study. Siam weed had green lacewings only until the 7th week, but none was observed in the rest of the period.

On associated plant species, Siam weed had the highest number of green lacewing. According to Walker *et al.* (2007) usually green lacewing populations will not increase largely in tangerine due to mortality that can result directly from contact with insecticides and/or indirectly from the consumption of insecticide-intoxicated prey. However, green lacewing population was found high on tangerine trees which increase from a mean of 2.5 to 4 per tree during 1-4 weeks, and then declined gradually. Siam weed too had two green lacewings at the beginning and decreased over time.

Tropical orb weaver spider: Tropical orb weaver population on tangerine associated with plant species was in a similar pattern, although the number varied among the plant species (Figure 2Ca). The highest tropical orb weaver population on tangerine was found with buffalo grass, high populations with cowpea, chilly pepper, moderate on goat weed and low in Siam weed and rice. The trend of population change remained nearly the same in all tangerine trees under each associated plant species.

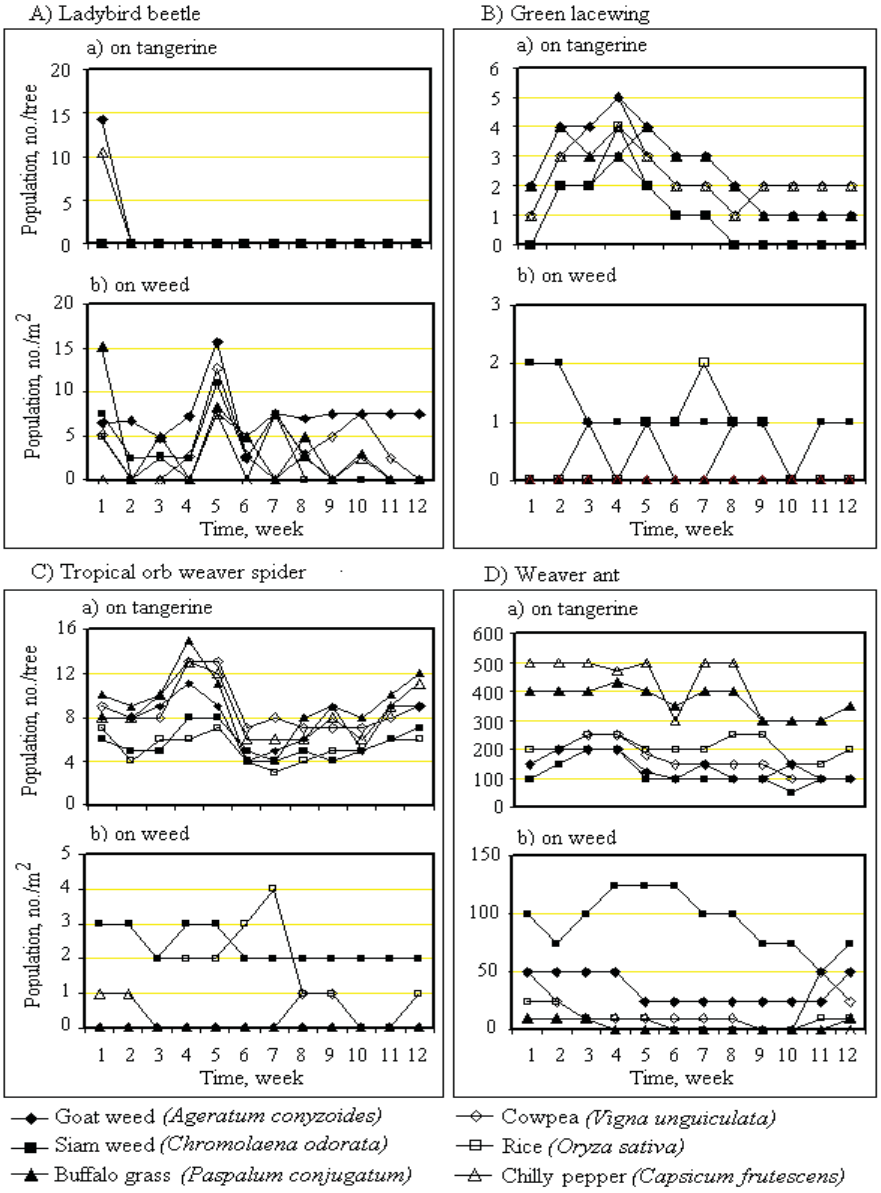
On associate plant species, Siam weed had the highest number of Tropical orb weaver, which is opposite of tangerine (Figure 2Cb). The same trend was also found on rice. Tangerine associated with rice had the lowest number of Tropical orb weaver, and its population fluctuations depicted the shifting of Tropical orb weaver between tangerine and the associated plants. Other plant species did not have Tropical orb weaver.

Weaver ant: Weaver ant is a major group of natural enemies of many plant pests. Their numbers were much higher on tangerine and often varied with the associated plant species (Figure 2Da). The populations of weaver ant was highest on tangerine when associated with chilly pepper (between 300 and 500/m2.), moderate on buffalo grass associated tangerine (300 and 430/m2.) and lowest on tangerine associated with the rest of the plant species (60 to 250/m2.).

Among the plant species, Siam weed had the highest weaver ant population (Figure 2Db). Goat weed had a moderate population, while the rest of the plants had low populations. The weaver ant population changed overtime such as on goat weed plant species started with 50 ants/m^2 was maintained until the 4th week, and then decrease by the 5th week to 25 ants/m^2 which remained unchanged until the 11th week. Weaver ants presence on Siam weed was high initially began with 100 ants/m^2, decreased at 2nd week and increasing again to 125 ants/m^2 by the 6th week and then gradually decreased to 75 ants/m^2 in the 12th week. Weaver ant presence on cowpea was low which initiated with 50 ants/m^2 and fluctuated during the 12 week study period. On rice, weaver ant population was low, and then numbers present at 1st and 2nd week were 25 ants/m^2 and again during 3rd-5th and 11th-12th weeks 10 ants/m^2 , and absent during 6th-10th weeks. Weaver ant on buffalo grass

was low with 10 ants/m² during 1st-3rd week and again in the 12th week. On chilly peppers, weaver ant

Figure 2. Selected natural enemy population on tangerine and associated plant species



population was at the lowest, but 10 ants were found during the 1st-3rd week.

Pest damage on tangerine

Asian citrus psyllid and Citrus white fly damage: There was a difficulty in distinguishing the damage on tangerine caused by citrus psyllid and citrus white fly due to their piercing and sucking nature of feeding, and the extent of damage of the two insects was shown in Figure 3a. Following the damage by the two insect pests further injury occurs due to infestation of sooty mold fungus which grows over fruits and foliage in the copious amount of honeydew excreted by the whitefly and nymphs and adults of psyllids. This molds coats leaves and reduces light interception by leaves thus reducing photosynthesis in plants. The greatest threat of Asian citrus psyllids is that it acts as vector transmitting the virus of citrus greening disease. The black fungus due to its rapid growth and covering affects physiological activities of the trees and developing fruits. Heavily-infested trees become weak and produce small crops of insipid fruit.

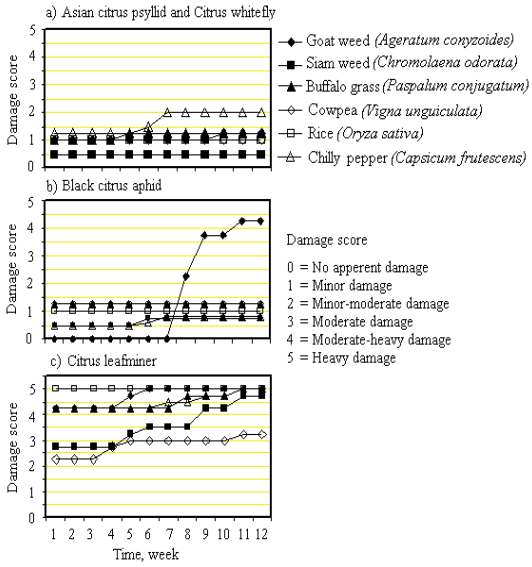
The damage on tangerine due to citrus psyllid and citrus white fly was minor in all associated plant species, except chilly peppers, and the latter caused minor-moderate damage on citrus since 7th week and continued until 12th week. In buffalo grass associated tangerine, there was a minor damage in the 1st week and a slightly higher damage during 5th to 12th weeks. The damage on tangerine in goat weed association was similar to that of buffalo grass, but slightly increased since 10th week and continued until 12th week. Cowpea and rice had the same degree of damage during 1st-12th week, yet it was minor. Siam weed showed the lowest damage of the two insects which remained throughout the experiment.

Black citrus aphid damage: The black citrus aphid damages host plants by feeding with piercing-sucking of mouthparts and extracting the plant sap from leaves, green shoots and flowers (Broughtom, 2007). Leaves may curl as a result of feeding. A large quantity of honeydew is also produced. Leaves and fruits often turn to black with the growth of the sooty mould fungus. The damage on tangerine by black citrus aphids was minor moderate-heavy damage (Figure 3b). Tangerine associate with goat weed had no damage in the first 7 weeks, but increased to moderate-heavy to heavy damage after 7th week. The reason that may due to low number of ladybird beetle, green lacewings and weaver ants on tangerine associated with goat weed at the latter part of experiment period, as ladybird beetle was presence only the 1st week and absent since the 2nd-12th week, green lacewings in the 1st week and gradually increased and peak occurred during 4th week and then decreased during 5th -8th week. Tropical orb weaver was abundant during 1st-5th week to 8-11/tree and decline during 6th-10th week. Again its population increased during 11th-12th week to 9/tree. Only weaver ants were abundant with of 150-200 /tree during 1st-4th weeks and decreased during 5th -12th week to 100-150/tree. Damage in buffalo grass and cowpea was minor to minor-moderate during the 12 week observation period. Rice caused minor damage during the 12 week period and Siam weed and chilly pepper had the lowest damage was below minor but above no apparent damage.

Citrus leafminer damage: Citrus leafminer larvae feed inside young leaves by creating shallow tunnels, referred to as mines. It is most commonly found on citrus. The larvae mine the lower or upper surface of the leaves causing them to appear curl and distorted. Citrus leafminer larva is likely to cause damage in nurseries new plantings on newly developing leaves. The growth of young trees is retarded by heavy infestations of citrus leafminer larvae. However, when its infestation is heavy, young trees are unlikely to die.

Citrus leafminer larvae damage was found on all tangerine trees associated with all plants, except Siam weed and cowpea. The latter had the lowest citrus leafminer larvae damage which was between minor-moderate to slightly above moderate (Figure 3c). During the first four weeks, Siam weed associated tangerine had between minor-moderate to moderate damage, which gradually increased to moderate and slightly above. The citrus leafminer larvae damage was heavy when the tree was associated with rice goat weed, buffalo grass and chilly and later increased with cowpea to heavy.

Figure 3. Asian psyllid and citrus whitefly (a) black citrus aphid (b) and citrus leafminer damage (c) on tangerine when associated with specific plants as undergrowth.



Discussion

Biodiversity refers to all species of plants, animals and microorganisms existing and interacting in an ecosystem (McNeely *et al.*, 1990) and can play a significant role, as prey and predator relationship usually helps reduce insect pests in crops. Altieri (1994) reported that orchards with rich floral undergrowth exhibit a lower incidence of insect pests than clean cultivated orchards, mainly because of an increasing abundance of predators and parasitoids which are capable of reducing pest populations. Therefore, designing and constructing vegetation architectures would be a useful approach to reduce populations of pest herbivores by increasing attraction of natural enemies.

The field investigation of the current study showed that there are more than 16 weed species growing underneath and around of the organically grown

tangerine trees, and that more than 24 insects living on both tangerine and on the 16 weed species. Of the 24 insects, Asian citrus psyllid, black citrus aphid, citrus leafminer and citrus whitefly were already reported as serious pests on tangerine (Nunta, 2000; Anon, 2010b), while ladybird beetle, green lacewing, tropical orb weaver spider and weaver ant as most effective predators and parasitoids (Morakot and Nunta, 1996; Nunta, 2000; Van Mele and Van Lenteren, 2002; Van Mele, 2008). Of the 16 weed species, three species namely Siam weed, goat weed and buffalo grass were found to attract both insect pests and natural enemies, and hence included for testing in the field experiment. The presence of these three weed species was considered to be effective in tangerine plantations.

In the field experiment, six plant species namely goat weed, Siam weed, buffalo grass, cowpea, rice and chilly pepper showed varying attractions of insect pests and natural enemies and their ability to manage tangerine pests through biological means. Tangerine had higher number of Asian citrus psyllids in all associated plant species, except Siam weed (Fig 1Aa). Except in buffalo grass, rice and chilly pepper, other plant species did not have Asian citrus psyllid (Fig 1Ab). On the other hand, the damage estimates were minor and minor-moderate by Asian citrus psyllid (Fig 3a). The key natural enemies of Asian citrus psyllid include ladybird beetle, green lacewings, tropical orb weavers and weaver ants; which also use as prey (Morakot and Nunta, 1996; Frank and Mizell, 2000; Nunta, 2000; Stoll, 2000; Van Mele, 2008). Among these, ladybird beetle was observed to be low in population on tangerine after the second week, and the number ranged from 2 to 15 on associated plant species. The relationship between Asian citrus psyllid and ladybird beetle is depicted in Figures 1A and 2A, which show the pest-enemy relationship with increasing Asian citrus psyllid on tangerine in the absence of ladybird beetle and decreasing Asian citrus psyllid population on associated plant species in the presence of ladybird beetle. Majumdar *et al.* (2009) also observed reduction in Asian citrus psyllid in the presence of ladybird beetles, lacewings, hoverflies and spiders. This nature of damage on pests by specific natural enemies (predators and parasitoids) is shown with black citrus aphid, citrus leafminer and citrus whitefly.

Crop damage estimate due to Asian citrus psyllid and citrus whitefly is usually at or below "minor", except in tangerine associated with chilly pepper which has "minor-moderate". It is hard to differentiate the crop damage caused by Asian citrus psyllid and citrus whitefly as both have piercing and sucking type of damage. Increased population of Asian citrus psyllid in tangerine when associated with chilly pepper was observed in Figure 1Aa and also with an enhanced damage in tangerine at "minor-moderate" level in Figure 3a. This could be attributed to specific attraction of Asian citrus psyllid by tangerine compared to chilly pepper. However, increased populations of green lacewings, tropical orb weaver spiders and weaver ant as enemies of Asian citrus psyllid may have positively contributed to the reduction of its damage, as these insects have been reported as natural enemies of Asian citrus psyllid and citrus whitefly (Frank and Mizell, 2000; Nunta, 2000; Stoll, 2000; Van Mele, 2008; Majumdar, 2009).

Although black citrus aphid population on tangerine trees was high, their damage on tangerine appeared to be "minor" (Fig 1Ba and b and Fig 3b). The black citrus aphid damage increased to "moderate to heavy" during 7th week on tangerine trees associated with chilly pepper. The same four natural enemies are known to be controlling the populations of black citrus aphid too (Morakot and Nunta, 1996; Futch *et al.*, 2002; Van Mele, 2008).

Citrus leafminer population and their damage were high on both tangerine and associated plants (Fig 3c). The damage scores show minor-moderate damage in tangerine associated with cowpea, moderate with Siam weed which showed greater attraction than other associated plant species, and moderate to high with the remaining plants (Figures 1C and 3c). Result show that citrus leafminers have not been effectively controlled by natural enemies. This could be due to the nature of feeding of citrus leafminer, as once an egg hatched, the larva enters between epidermal tissues at immature leaves and hence not visible or vulnerable to natural enemies.

The effects of associated plant species indicate that there is a varying attraction of specific insects by such plants, thus varying the level of crop damage. All plants, except chilly pepper, effectively reduced the damage by black citrus aphid and citrus whitefly. Similarly, all plants, except goat weed, had lower damage. With respect to citrus leafminer, all plants, except cowpea caused a greater damage.

Pest attraction and repellence are two ways by which the associated plant species could modify the behavior of insect pests on specific plants (Vandermeer, 1989; Anon, 2010b). The associated low growing plant species could reduce the damage on economic plants by attracting some pests and keeping them away from tangerine trees. However, there has been variation in pest populations on both tangerine and associated plants species during the study period. This could also be attributed to palatability of the host plants which decreases overtime as the plant matures, which is determined by the environmental conditions such as moisture and temperature as both have special influence on plant growth (Rao, 2000).

Therefore, different plant species inhabiting in tangerine plantations could modify the population of different insect pests and their threats based on the degree of attraction or repellence. There are many reasons for insect attractions suggested by the previous researchers: smell such as volatile allelochemicals in the goat weed (Kong *et al*., 2005; Unsicker, Kunert and Gershenzon, 2009; McPartland and Clarke, 2000.), oil (Menut *et al*., 2006; Owolabi *et al*., 2010), color (Demirel and Cranshaw*, 2006*), palatability (Modder, 1984) glucan in Siam weed (Zhao, Zhang and Liu, 2010) [the glucan content of the weed stem was similar to that of sugarcane bagasse, but higher than those of corn stover and wheat straw], etc. In the same manner, the opposite, i.e. repelling insect pests by several plant species, has also been reported (Kianmatee and Ranamukhaarachchi, 2007a and 2007b). However in the management of pest in tangerine, if would be more appropriate to explore the plant species having pest attraction.

The current study clearly demonstrated the pest attraction of goat weed, Siam weed, buffalo grass, chilly pepper, cowpea and rice. Therefore, keeping the first three plants as weeds and/or growing the latter three crops as under-storey crops in tangerine plantations could reduce pest populations and their damage on tangerine. This will help reduce pesticide use and health risks associated with heavy use of highly toxic pesticides in tangerine. This will also relieve people residing in tangerine cultivated areas in the Fang watershed as well as other areas in Thailand.

Conclusion

The current study sought a solution to pesticide-based insect pest management in tangerine as heavy use of heavily toxic persistent pesticides imposed adverse effects on people residing in the vicinity of tangerine plantations by frequently breathing pesticide contaminated air and consumers due to pesticide contaminated fruits and pollution of environment. The study concentrated on four common insect pests - Asian citrus psyllids, black citrus aphids, citrus leafminers and citrus whiteflies - and four natural enemies – ladybird beetle, green lacewings, tropical orb weaver and weaver ants. The study evaluated three weeds from the weed flora - goat weed, Siam weed and buffalo grass, and three crops – rice, cowpea and chilly pepper - for insect pest and natural enemy to enhance the biological management of tangerine pests.

The results showed that chilly pepper and buffalo grass attracted all insect pests, except black citrus aphid. The former attracted ladybird beetle and tropical orb weaver, while the latter attracted all four selected natural enemies. Rice attracted all insect pests, except black citrus aphids, and all natural enemies. Siam weed too attracted all natural enemies and insect pests, except Asian citrus psyllids. Both cowpea and goat weed attracted citrus leafminer and citrus whiteflies among the four insect pests and ladybird beetle and weaver ants among the four concerned natural enemies. The leafminer damage on tangerine was minor-moderate to heavy and varied with the associated weed species. Therefore, these findings confirmed the potential for managing tangerine pests by growing pest attractive plants and with natural enemies without frequent reliance on heavily toxic long persisting pesticides.

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References

Altieri, M. A., A. V. Schoonhoven and J. D. Doll. 1977. The ecological role of weed in insect pest management systems: A review illustrated with bean (Phaseolus vulgaris L.) cropping systems. PANS, 23: 195-205.

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

Altieri, M. A. and W. H. Whitcommb. 1980. Weed manipulation for insect management in corn. Environmental Management, 4: 483-489.

Altieri, M. A. and L. L. Schmidt. 1985. Cover crop manipulation in northern California orchards and vineyards: effects on arthropod communities. Biological Agriculture and Horticulture, 3: 1-24.

Altieri, M. A. 1994. Biodiversity and Pest Management in Agroecosystems. Food products press. An Imprint of The Haworth press, Inc. 185P.

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

Andrews, G., S. Stewart and M. Williams. 1997. Cotton Insect Situation, No.11, 17(7). Mississippi State University Extension Service. Available at: http://www.search.mississippi.gov/query.html?qt=url%3Amsucares.com/newsletters/pests/cis+%7C%7C&st=91 (Accessed 2010 June 26).

Anon, 1998. Upper soil. Second book. Report on soil management for main economic planting. Land

Development Department, Ministry of Agriculture and Cooperative Thailand. Available at: http://www.ldd.go.th/pldweb/tech/electronic_doc/index.htm (Accessed 2010 April 09).

Anon, 2008. Citrus. Citrus Leafminer . How to Manage Pests UC Pest Management Guidelines.

Anon, 2009. Citrus commodity survey reference. Commodity Reference Guides, CAPS-Cooperative agriculture pests survey, USDA. Available at: http://www.aphis.usda.gov/plant_health/plant_pest_info/pest_detection/downloads/citrus-cr.pdf (Accessed 2010 April 10).

Anon, 2010a. Rain data. Northern Meteorological Center, Chiang Mai, Thailand. Available at: www.cmmet.tmd.go.th/excel/rain_data.xls (Accessed 2010 July 04).

Anon, 2010b. Pepper. Online information service for non-chemical pest management in the tropics. PAN. Available at: http://www.oisat.org/crops/vegetables /pepper.html (Accessed 2010 June 02).

Aubert, B. 1990. Prospects for citriculture in Southeast Asia by the year 20000. FAO Plant. Bull. 38. 151-173.

Bedford, E.C.G., M. A. Van den Berg and E. A. De. Villiers. 1998. Citrus Pests in the Republic of South Africa. The ARC Institute for Tropical and Subtropical. 228P.

Broughtom, S. 2007. Aphids in citrus, Farm note: 242. Department of agriculture and food, Government of Western Australia. Available: http://www.agric.wa.gov.au, page 1 (Accessed 2009 Dec. 24).

Chapman, R. F. 1998. The insects: structure and function, 4th Edition, Cambridge university press, 788P.

Demirel, N. and W. Cranshaw. 2006. Relative attraction of color traps and plant extracts to the false chinch bug Nysius raphanus and its parasitoid, Phasia occidentis, on brassica crops in Colorado. Phytoperasitica, 34(2):197-203.

Fasulo, T. R. 2007. Citrus whitefly. Department of Agriculture and Consumer Services, Division of Plant Industry, University of Florida and Howard V. Weems, Florida. Available: http://entnemdept.ufl.edu/creatures/citrus/citrus_whitefly.htm.(Accessed 2010 April 10).

Frank, J. H and R. F. Mizell. 2000. Ladybird beetles. University of Florida. EENY-170. Available at: http://www.entnemdept.ufl.edu/creatures/beneficial/ladybeetles. htm (Accessed 2010 June 27).

Futch, S. H, C. W. McCoy, J. P. Michaud and C. C. Childers. 2002. A Guide to Identification of Soft-bodied Citrus Insect Pests. HS-870. Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Available at: http://edis.ifas.ufl.edu/hs133 (Accessed 2010 June 27) .

Haynes, R. J. 1980. Influence of soil management practice on the orchard agroecosystem. Agro-ecosystems, 6: 3-32.

Heinrichs, E. A. 2009. Management of Rice Insect Pests. IPM world textbook, the University of Minnesota. Available at: http://ipmworld.umn.edu/chapters /heinrich.htm (Accessed 2010 June 02).

Jamornmarn, S. 1997. Insect ecology. Entomology. Kasetsert university, Thailand. 89P.

Joemsiri, J. and J. Pannim. 2000. Insect Pests in Fruit trees, Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand. 86P.

Jungbluth, F. 2000. Economic Analysis of Crop Protection in Citrus Production in Central Thailand, A Publication of the Pesticide Policy project, Hannover, 156P.

Khan, Z. R., K. Ampong-Nyarko, P. Chiliswa, A. Hassanali, S. Kimani, W. Lwande, W. A. Overholt, W. A. Overholt, J. A. Picketta, L. E. Smart and C. M. Woodcock. 1997. Intercropping increases parasitism of pests. Nature, 388: 631– 632.

Khuankaew, O. 1995. IPM and Women. Report on short Term Consultancy, Integrated Pest Management in Selected Fruit Trees Project. Thai-German Plant Protection Programme, Department of Agricultural Extension. Bangkok. Thailand.

Kianmatee, S. and S. L. Ranamukhaarachchi. 2007a. Combining Pest Repellent Plants and Biopesticides for Sustainable pest Management in Chinese kale. J. Asia-Pacific Entomol. 10(1): 69-74.

Kianmatee, S. and S. L. Ranamukhaarachchi. 2007b. Pest repellent Plants for Management of Insects Pest of Chinese kale, Brassica Oleracea L. International J. of Agriculture & Biology, 9(1): 64-67.

Kong, C., F. Hu, and X. Xu. 2002. Allelopathic Potential and Chemical Constituents of Volatiles from Ageratum conyzoides Under Stress. J. of Chemical Ecology, 28(6):1173-1182.

Kong, C., F. Hu, X. Xu, M. Zhang, and W. Liang. 2005. Volatile allelochemicals in the Ageratum conyzoides Intercropped Citrus Orchard and their Effects on Mites Amblyseius newsami and Panonychus citri. J. of Chemical Ecology, 31(9): 2193-2203.

Leius, K. 1967. Influence of wild flowers on parasitism of tent caterpillar and codling moth. Canadian Entomologist, 99: 444-446.

Majumdar, A. 2009. Asian Citrus Psyllid. Agronomic Crops and Commercial Horticulture, Aubum university. Monte Nesbitt, Horticulturist, Gulf Coast Research Extension Center, and Henry Fadamiro ANR-1341 Web Only. Available at: http://www.aces.edu /pubs/ New April 2009 (Accessed 2010-April 12).

Malaipun, S. 1995. Basic Practical on Entomology. Entomology division. Kasetsert university, Thailand. 265P.

McNeely, J. A., K. R. Miller, W. V. Reid, R. A. Mittermeier, and T. B. Werner. 1990. Conserving the world biological diversity. International union for conservation of nature and Natural Resources. WRI. Consv. Intl.. World Wildlife Funders. World Bank. Washington. DC.

McPartland, J. M. and R. C. Clarke. 2000. Hemp diseases and pests: management and biological control.184P.

Menut, C., G. Lamaty, P. H. A. Zollo, J. R. Kuiate, and J. M. Bessiere. 2006. Aromatic plants of tropical central Africa. Part X Chemical composition of the essential oils of Ageratum houstonianum Mill. and Ageratum conyzoides L. from Cameroon. Flavour and Fragrance Journal, 8(1): 1 – 4.

Modder, W. W. D. 1984. The attraction of Zonocerus variegatus (L.) (Orthoptera: Pyrgomorphidae) to the weed Chromolaena odorata and associated feeding behaviour. Bulletin of Entomological research 4: 239-247.

Morakot, R. and P. Nunta. 1996. Predator-Parasitoid Real Friend of Citrus Grower. Working group for biological pests management. Entomology and Zoo Division, Department of Agricultural, Thailand. 98P.

Namrungsri, W., S. Vichitranon, J. Manussakorn, S. Lertwatanakiat and T. Salapraveat. 2005. Diseases and Pests of Citrus. Horticultural Institute. Department of Agriculture, Ministry of Agriculture and Cooperatives Thailand. 40P.

Nunta, P. 2000. Biological control of insect pests for sustainable agriculture. Entomology and Zoo Division, Department of Agricultural, Thailand. 317P.

Owolabi, M. S., A. Ogundajo, K. O. Yusuf, L. Lajide, H. E. Villanueva, J. A. Tuten and W. N. Setzer. 2010. Chemical Composition and Bioactivity of the Essential Oil of Chromolaena odorata from Nigeria. Rec. Nat. Prod., 4(1): 72-78.

Paradornuwat, A., K. Jaroensom, C. Ounahawut. 1999. Insects and Pest Mites in Tangerine, Tangerine. Kasetsert university, Thailand. 181P.

Rao, V. S. 2000. Biological approaches in weed management, Principles of weed science. Science publishers, Inc. USA. 320P.

Sinhaseni, P. 1994. Toxicological Concepts, Regulatory Provision and Appropriate Technology for Pesticide Safe Use: an Experience in Thailand. Bangkok: Pesticide Safe Use Unit, Faculty of Pharmaceutical Sciences, Chulalongkorn University, Thailand.

Stoll, G. 2000. Natural Crop Protection in the Topics. Margraf Verlag. 376P.

UC ANR Publication 3441. Available at: http://www.ipm.ucdavis.edu/PMG/r107303211. html (Accessed 2010 April 09).

Unsicker, S. B., G. Kunert, and J. Gershenzon. 2009. Protective perfumes: the role of vegetative volatiles in plant defense against herbivores. Current Opinion Plant Biology, 12(4): 479-485.

Vandermeer, J. 1989. The ecology of intercropping. Cambridge University Press, Cambridge, MA. 237P.

Van Emden, H. F. and G. F. Williams. 1974. Insect stability and diversity in agroecosystem. Annual Review of Entomology, 19: 455-475.

Van Emden, H. F. 1965. The role of uncultivated land in the biology of crop pests and beneficial insects. Scientific Horticulture, 17: 121-136.

Van Mele, P. and J. C. Van Lenteren. 2002. 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. Agriculture Ecosystem and Enveronment, 88:35-48.

Van Mele, P. 2008. historical review of research on the weaver ant Oecophylla in biological control. Agricultural and Forest Entomology, 10:13–22.

Waterhouse, D. F. 1994. Biological control of weeds: Southeast Asian Prospects. Australian Center for International Agriculture Research. 302P.

Walker M. K., M. A. W. Stufkens and A. R. Wallace. 2007. Indirect non-target effects of insecticides on Tasmanian brown lacewing (Micromus tasmaniae) from feeding on lettuce aphid (Nasonovia ribisnigri). Biological Control, 43(1):31.

Weeden, C. R., A. M. Shelton, and M. P. Hoffman, 2007. Biological Control: A Guide to Natural Enemies in North America. Cornell University. Available: http://www.nysaes.cornell.edu/ent/ biocontrol/ (Accessed 2010 April 09).

Yimsaman, M. 2004. Environment changed from tangerine orchard: in case of Tambon Monpin. Fang district. Chiang Mai. Thailand. Report. 50P.

Zhao, X., L. Zhang and D. Liu. 2010. Pretreatment of Siam weed stem by several chemical methods for increasing the enzymatic digestibility. Institute of Applied Chemistry, Department of Chemical Engineering, Tsinghua University, Beijing, China. Biotechnol J. 5:493-504.