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The weaver ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae), an effective biological control agent of the red-banded thrips, *Selenothrips rubrocinctus* (Thysanoptera: Thripidae) in mango crops in the Northern Territory of Australia

(*Keywords:* weaver ant, red-banded thrips, biological control, mango, *Oecophylla smaragdina*, *Selenothrips rubrocinctus*)

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Abstract. Weaver ants, *Oecophylla smaragdina* (Fabricius), have been successfully used to control the main insect pests of cashew plantations in northern Australia and Papua New Guinea. The red-banded thrips, *Selenothrips rubrocinctus* (Giard), is an economically important insect pest of mango, *Mangifera indica* L., orchards in the Northern Territory. This work was undertaken to evaluate whether weaver ants, which are abundant in mango orchards, have the potential to control the red-banded thrips. Field surveys, field experiments and laboratory trials were carried out in four mango orchards in the Darwin area over four years. In field surveys, the number of shoots damaged by the thrips was significantly lower on trees with abundant weaver ants (2.8%) than with fewer ants (21.1%), or without the ants (30.3%). Trees with abundant weaver ants also produced the highest numbers of flower panicles. Leaf examinations revealed that newly mature leaves on trees with abundant weaver ants had significantly fewer thrips than on trees with fewer or no ants. Field experiments showed that weaver ants were as effective as chemical insecticides in limiting fruit damage by thrips. In laboratory trials, seedlings without weaver ants were heavily damaged, and lost all their leaves within six weeks, while seedlings with weaver ants grew well and lost no leaves. This work suggests that the weaver ant is an effective biological control agent of the red-banded thrips, and the use of weaver ants in mango orchards is discussed.

1. Introduction

The red-banded thrips, *Selenothrips rubrocinctus* (Giard) (Thysanoptera: Thripidae), is one of the world's major insect pests, damaging a range of tropical and sub-tropical tree crops, such as mango, cashew, avocado, cacao, guava, mangosteen, rambutan, tung-oil tree and many kinds of ornamental trees (Callan, 1975, Bennett and Baranowski, 1982, Igboekwe, 1985, Dennill, 1992, Patel *et al*., 1997). It is an economically important pest in orchards of mango, *Mangifera indica* L., in the Northern Territory of Australia (Poffley, 1996, Young and Poffley, 1997, Young and Chin, 1998). Red-banded thrips are normally abundant between April and July (Young and Chin, 1998), when they cause serious damage to newly mature leaves, and they also damage new leaf flush and fruits, resulting in fallen leaves, denuded trees and inferior fruits. More importantly, leaf damage in the pre-flowering flush can lead to a significant reduction of flower panicles produced by trees (Malcolm Green, Anna Couttie, Hannah Couttie, Les Brigden and Diane Lucas, 2001, pers. comm.).

Red-banded thrips usually occur in mango orchards together with other insect pests such as leafhoppers, fruit-spotting bugs, leaf beetles and caterpillars. To control red-banded thrips and other insect pests, conventional mango growers in the Northern Territory rely on chemical insecticides such as Trichlorfon and Dimethoate, using 6 – 8 sprays between March and August. The pest populations can be controlled, but the heavy use of insecticides has resulted in increased costs, the reduction of natural predators and parasitoids of the insect pests, increased insect pest resistance to insecticides and environmental pollution (Ian Baker, pers. comm.). Some organic mango growers use commercial predators (e.g. the lacewing, *Mallada signata* (Schneider), (Neuroptera: Chrysopidae) to control the thrips. Adequate control can be achieved if the predators are released in sufficient numbers at the right time, but this operation is very expensive due to the costs of the predators ($Aus550/ha for two releases) and the required monitoring programme. Other organic growers take no action against the thrips, and their trees are damaged, resulting in reduction of yield and fruit quality (Malcolm Green, Anna Couttie, Hannah Couttie, and George Sohn, 2001, pers. comm.). Thus, taking no action against thrips is not economically viable.

Weaver ants, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae), are known to control over 40 species of insect pests on many tropical tree crops (Way and Khoo, 1992, Peng *et al*., 1995, 2000a). This ant lives in leaf nests in the canopy of many tropical trees, and it feeds on sugar-rich materials and a range of insects by patrolling various parts of trees. Barzman *et al*. (1996), Van Mele and Cuc (2000) and Van Mele *et al*. (2002) suggested that weaver ants could be used in citrus orchards in Vietnam. Since 1998, weaver ant colonies have been successfully used to control the main insect pests in cashew orchards in the Northern Territory and Papua New Guinea (Peng *et al*., 1999, 2000b, Peng, 2001). This species of ant occurs abundantly in mango orchards in the Northern Territory, and therefore, they may have the potential to reduce red-banded thrips populations.

2. Materials and Methods

Four mango orchards in the Darwin (12° 40′S 130° 81′E) area of the Northern Territory were used in this study in 1996, 1997, 2001 and 2002. Orchards A, B and C are 22 km, 29 km and 23 km respectively south-east of Darwin, and orchard D is

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38 km south-south-east of Darwin. The trees were between four and seven years old, and were of the Kensington Pride variety. Field surveys, field experiments and laboratory trials were used in this study.

2.1. Field survey (assessment of thrips numbers)

Two field surveys (one survey in March and the other in May) were performed in orchard A in 1996. In March, when the red-banded thrips populations were increasing, every tree in a mango block of 0.5 ha was sampled. A total of eight newly mature leaves (most recently hardened flush) were picked from four sides of a tree (two on each side) using a picking pole, and each leaf was put in a small plastic bag. The bagged samples were immediately taken to the laboratory and the red-banded thrips (nymphs and adults) on each leaf and in the plastic bag were counted under a binocular microscope. Weaver ant abundance on each tree was assessed at the same time. The number of ant trails on the main branches of a tree was counted while tapping the tree trunk with a stick, and the total number of main branches on the tree was also recorded. The percentage of the main branches with ant trails was calculated for each tree. Weaver ants on a tree were treated as 'Abundant', if $\geqslant 50\%$ of the main branches had ant trails, or as 'Fewer ants' if $< 50\%$ of the main branches had ant trails. Some trees, which were heavily foraged by the ground nesting meat ant, *Iridomyrmex sanguineus* (Forel) (Hymenoptera: Formicidae), were recorded as 'trees with meat ants'.

In May, when the thrips populations were large, every tree in a block of 0.7 ha (including the 0.5 ha used in March) was sampled. Five newly mature leaves per tree were picked (one on each side and one at the top), and the same procedures that were carried out in March were performed. Thrips numbers among four categories (trees with abundant weaver ants, with fewer weaver ants, with meat ants and without ants) were analysed by a Kruskal-Wallis one-way ANOVA by ranks (non-parametric) (Siegel, 1956) using SYSTAT statistical software (Wilkinson, 1990).

2.2. Field survey (assessment of damaged shoots)

Red-banded thrips are abundant between April and July in the Northern Territory (Young and Chin, 1998), and field surveys were performed between May and July. A total of eight field surveys were conducted: five in orchard A in 1996, 1997, 2001 and 2002, two in orchard B in 2002 and one in orchard D in 2001. In each survey, every tree in an orchard was inspected. For each tree, all the shoots in the outer-middle area of the tree were examined, which is where the thrips are most abundant (Young and Chin, 1998). The thrips prefer to feed on the tissue next to the midrib on the undersurface of newly mature leaves. The sign of fresh damage is silvering patches on leaves with numerous small, shiny black spots of excreta, and then the silvering develops a pale-yellow to brown discolouration, speckled darkly with dried droppings. In the assessment of shoot damage, two variables were used: the total number of newly mature leaves on a shoot, and the number of damaged leaves. A leaf was treated as 'damaged' if more than 30% of the whole leaf area had signs of fresh damage, otherwise the leaf was classified as 'not damaged'. Based on our field observations, when more than 30% of a leaf area was damaged the leaf gradually turned brown, dried and dropped from the tree. This did not occur when less than 30% of a leaf area was infested by thrips. If the damaged leaves represented more than 30% of the newly mature leaves on a shoot, the shoot was recorded as 'damaged', otherwise it was considered 'not damaged'. According to our observations, shoots often bear more than 10 newly mature leaves. If a shoot had more than 30% of the leaves 'damaged', the shoot gradually became denuded; otherwise the shoot did not become denuded. Percentage of damaged shoots per tree was calculated as follows: total number of damaged shoots/ total number of shoots in the outer-middle area of the tree $\times$ 100. The abundance of weaver ants and other species of ants on each tree was assessed at the same time as the assessment of leaf shoots, and the criteria used for the assessment are given above. The damage by the thrips was compared for groups of trees (those with abundant weaver ants, fewer weaver ants, other species of ants, and no ants) using the Kruskal–Wallis one-way ANOVA by ranks (Siegel, 1956).

2.3. Field experiment

Field experiments were done in orchards A and C in 2001 and 2002. In orchard A, during the mango pre-flowering flush in May 2001, a 1.4 ha mango block was equally divided into three replicates, and each replicate had two treatments. One treatment had weaver ants present, and the other had no weaver ants present but chemical insecticides were used. In the weaver ant treatment, the ants attend mealybugs for honey dew, and mealybug populations were high and caused damage on fruits. To reduce this damage, one of two 'soft' chemicals (Petroleum spray oil (D.C. Tron Plus) at 1.5% v/v or Potassium Soap at 1% v/v), both of which have little effect on weaver ants, was used when 5–10% of fruits were infested by mealybugs. In the treatment with chemical insecticides, Lepidex 500 (500 g/ L Trichlorfon) at 0.1% v/v and/or Dimethoate (400 g/L Dimethoate) at 0.1% v/v were used when insect pests caused a damage of 5–10% of foliar or floral shoots or developing fruits (acceptable levels by mango growers). Therefore, this block had two treatments, and each treatment had three replicates, each of which had between 32 and 43 mango trees of similar size and age. Weaver ants were transplanted into each of the three 'with weaver ant' replicates in May 2001. Monitoring of the main insect pests and the ant abundance in each replicate started early June 2001 and was done once a week during the pre-flowering flush and flowering and fruiting flush and once a month at other times. During the mango harvest, every fruit was assessed on site, based on the Mango Quality Standards produced by the Queensland Mango Sub-committee and H.R.D.C. for the Mango Growers of Australia, which is the standard assessment used by mango packing sheds in the Northern Territory. If a fruit had an area greater than 3 cm^2 of thrips damage (silvery patches with numerous small, shiny black spots of excreta) on its skin, the fruit was treated as 'damaged'.

In orchard C, 38 mango trees occupying an area of 0.4 ha were used. Based on the distribution of existing weaver ant colonies, the orchard was divided into three treatments. The first treatment included 12 trees, which had weaver ants present and were treated with 'soft' insecticides (D.C. Tron Plus at 1.5% v/v or Potassium Soap at 1% v/v was used when 5–10% of fruits were infested by mealybugs). The second treatment included 13 trees, which had weaver ants present but were not treated with chemicals. The third treatment included 13 trees, which had no weaver ants present and no soft chemicals or chemical insecticides were used. The procedures of monitoring and fruit quality assessment were the same as in orchard A.

For orchard A, a two-way ANOVA was used to examine the effect of two treatments (trees with weaver ants plus 'soft' chemicals and trees with chemical insecticides) in the three replicates. An arcsine (square root) transformation was applied to the percentage damage of fruit to achieve normal distributions before the ANOVA was conducted. In orchard C, percentage of fruit damage was analysed by the Kruskal-Wallis one-way ANOVA by ranks (Siegel, 1956).

2.4. Laboratory trial

Two laboratory trials were performed at the Charles Darwin University campus in 2001 and 2002 to determine the effects of weaver ants on red-banded thrips. In 2001, cashew seedlings were used to rear the thrips because (1) both cashew and mango are red-banded thrips hosts, and (2) at the time of the trial, mango seedlings were not available. Each flower pot had a cashew seedling grown from seed, and 10 pots with seedlings were prepared. When seedlings were 4 weeks old and had about 6–7 leaves, each seedling was inoculated with 26–60 nymphs of red-banded thrips, depending on the number of leaves on the seedling. Red-banded thrips were collected from mango trees in orchard A. To transplant the thrips, a piece of leaf with a known number of thrips larvae (which had been counted under a binocular microscope) was attached to a leaf on a seedling. After the inoculation, the ten seedlings were kept in an entomological laboratory at 25–28°C for 3 days to allow the thrips to move to cashew leaves.

On the fourth day, the 10 pots were taken to a well-established weaver ant colony. Each pot was put in a saucer filled with water. Five of these pots were put on one side of the main weaver ant trail, and the weaver ants were kept away from the cashew seedlings by the water in the saucers. Another five seedlings were put on the other side of the ant trail, and these saucers were filled with a combination of water and gravel, so the ants were able to walk on the gravel to reach the seedlings. Because the seedlings were too small for the ants to construct nests, two small weaver ant nests (which were taken from the adjoining colony) were transferred onto each seedling pot every week. The number of nymphs and adults of red-banded thrips on each seedling and the growth of the cashew seedlings were recorded prior to introducing new ant nests each week.

In 2002, mango seedlings were used in the laboratory trial. These seedlings were affected by red-banded thrips by the time they had 6–8 leaves. The number of nymphs and adults of red-banded thrips on each of the seedlings was counted at the beginning of the trial. The procedures of this trial were the same as the 2001 trial. Unfortunately, this experiment was stopped in week 5 because irrigation was accidentally started, which affected the thrips numbers on the seedlings and the foraging behaviour of the ants. As data for both trials did not meet the requirement of parametric *t*-test assumptions, the data were analysed by the Mann–Whitney *U*-test (Siegel, 1956) using non-parametric statistics software (Wilkinson, 1990).

3. Results

3.1. Field survey (assessment of thrips numbers)

In orchard A in March 1996, the average number of thrips found on a new mature leaf was significantly lower in trees with abundant weaver ants (0.3) than in trees with fewer weaver ants (2.9), or in trees with meat ants (1.4), or in trees without ants (3.5) (table 1). Similar results were observed in May when the red-banded thrips populations were high (table 1).

3.2. Field survey (assessment of damaged shoots)

In orchard A, data from May 1996 demonstrated that 3.8% of shoots in trees with abundant weaver ants were damaged by red-banded thrips, which was much lower than in trees with meat ants (27.1%) or in trees without ants (64.7%) (table 2a). Data from surveys done in July 1997 and in June 2001 revealed that trees with abundant weaver ants were much less damaged by the thrips than trees with fewer weaver ants or without weaver ants (table 2). This characterization holds true for the survey done in June and July 2002 (table 3a). Also, in the July 2002 survey, trees with abundant weaver ants produced the most flower panicles (table 3a).

Table 1. Populations of red-banded thrips in orchard A in 1996

	15 March 1996		3 May 1996	
Trees with	Mean number of thrips/leaf ± SD[1]	N[2]	Mean number of thrips/leaf ± SD	N
Abundant *Oecophylla smaragdina*	0.3 ± 0.6	208	2.8 ± 3.8	150
Fewer *O. smaragdina*	2.9 ± 4.9	48	3.2 ± 2.9	50
Iridomyrmex sanguineus	1.4 ± 2.2	168	17.0 ± 18.8	65
No ants	3.5 ± 2.7	48	12.6 ± 8.3	145
Kruskal–Wallis test	$H=19.4$, df = 3, $p < 0.001$		$H=28.3$, df = 3, $p < 0.001$	

[1] SD refers to the standard deviation of the mean.
[2] N refers to the number of newly mature leaves examined.

Table 2. Damage caused by red-banded thrips in (a) orchard A in 1996 and 1997 and (b) two orchards in June 2001

(a)

	May 1996		July 1997	
Trees with	Mean % damaged shoots/tree ± SD [1]	N [2]	Mean % damaged shoots/tree ± SD	N
Abundant *Oecophylla smaragdina*	3.8 ± 1.3	32	1.3 ± 2.8	24
Fewer *O. smaragdina*	–		3.7 ± 5.8	13
Iridomyrmex sanguineus	27.1 ± 4.9	21	–	
No ants	64.7 ± 10.1	6	19.2 ± 23.5	20
Kruskal–Wallis test	$H = 35.4$, df = 2, $p < 0.001$		$H = 10.3$, df = 2, $p < 0.01$	

(b)

	Orchard A		Orchard D	
Trees with	Mean % damaged shoots/tree ± SD [1]	N [2]	Mean % damaged shoots/tree ± SD	N
Abundant *O. smaragdina*	5.2 ± 8.0	22	2.6 ± 2.6	12
Fewer *O. smaragdina*	28.4 ± 24.3	10	–	
Iridomyrmex sanguineus	6.2 ± 8.5	5	17.5 ± 13.1	4
Iridomyrmex sp	–		35.2 ± 29.9	18
No ants	41.2 ± 32.6	8	–	
Kruskal–Wallis test	$H = 18.3$, df = 3, $p < 0.001$		$H = 17.2$, df = 2, $p < 0.001$	

[1]SD refers to standard deviation of the mean.
[2]N refers to the number of trees examined.

Table 3. Damage caused by red-banded thrips in (a) orchard A and (b) orchard B in 2002

(a)

	5 June 2002		3 July 2002		
Trees with	Mean % damaged shoots/tree ± SD [1]	N [2]	Mean % damaged shoots/tree ± SD	Number of flower panicles/tree ± SD	N
Abundant *Oecophylla smaragdina*	0.5 ± 1.1	75	3.1 ± 7.1	63.2 ± 52.2	55
Fewer *O. smaragdina*	13.0 ± 14.7	20	36.4 ± 27.0	8.8 ± 9.0	29
Iridomyrmex sanguineus	8.6 ± 11.8	4	23.6 ± 10.7	52.9 ± 20.6	7
Iridomyrmex sp	19.4 ± 18.3	5	48.0 ± 37.4	22.8 ± 15.1	5
No ants	33.2 ± 23.6	22	56.1 ± 25.2	4.4 ± 6.3	18
Kruskal–Wallis test	$H = 79.5$, df = 4, $p < 0.001$		$H = 71.0$, df = 4, $p < 0.001$	H = 68.6, df = 4, $P < 0.001$	

(b)

	28 May 2002		10 July 2002		
Trees with	Mean % damaged shoots/tree ± SD [1]	N [2]	Mean % damaged shoots/tree ± SD	Number of flower panicles/tree ± SD	N
Abundant *O. smaragdina*	1.7 ± 3.2	46	6.6 ± 9.9	91.7 ± 67.5	46
Fewer *O. smaragdina*	13.6 ± 15.6	7	18.6 ± 25.4	28.7 ± 17.4	7
Iridomyrmex sp	38.6 ± 18.5	6	22.2 ± 19.3	63.8 ± 48.3	7
No ants	29.6 ± 26.6	18	26.6 ± 18.5	26.9 ± 29.2	17
Kruskal–Wallis test	$H = 38.9$, df = 3, $p < 0.001$		$H = 23.9$, df = 3, $P < 0.001$	$H = 28.9$, df = 3, $P < 0.001$	

[1]SD refers to standard deviation of the mean.
[2]N refers to the number of trees examined.

Similarly in orchard B, trees with abundant weaver ants were also significantly less damaged by red-banded thrips than trees with fewer weaver ants or without weaver ants (table 3b). In addition, trees with abundant weaver ants also produced the highest number of flower panicles (table 3b).

In orchard D, trees with abundant weaver ants were damaged significantly less by red-banded thrips than trees with other species of ants (table 2b).

3.3. Field experiment

In 2001, the thrips damaged a higher proportion of the fruit from trees treated with chemical insecticides (3.9%) compared with trees with weaver ants plus 'soft' chemicals (0.9%, table 4a). There was no difference among replicates ($p = 0.76$) and no significant interaction between treatments and replicates ($p = 0.75$). In 2002, there was no difference in the proportion of

Table 4. Red-banded thrips damage on mango fruits in different treatment in (a) orchard A and (b) orchard C

(a)

Treatment	Replicates	2001 % fruit damage ± SD[1]	2001 N[2]	2002 % fruit damage ± SD	2002 N
Chemical insecticide	3	3.9 ± 6.8	66	0.4 ± 1.2	117
Oecophylla smaragdina and soft chemicals	3	0.9 ± 2.7	45	0.2 ± 0.7	80
ANOVA		$F = 10.8$, df = 1, $p = 0.001$		$F = 0.4$, df = 1, $p = 0.518$	

(b)

Treatment	2001 % fruit damage ± SD[1]	2001 N[2]	2002 % fruit damage ± SD	2002 N
Oecophylla smaragdina only	0.1 ± 0.2	13	0.1 ± 0.2	12
O. smaragdina and soft chemicals	0.1 ± 0.2	11	0.0 ± 0.1	12
No *O. smaragdina* and no soft chemicals	1.3 ± 1.5	11	0.8 ± 0.8	13
Kruskal–Wallis test	$H = 11.7$, df = 2, $p = 0.003$		$H = 10.1$, df = 2, $p = 0.006$	

[1]SD refers to standard deviation of the mean.
[2]N refers to the number of trees assessed.

fruit damaged from trees treated with chemical insecticides (0.4%) compared to fruits from trees with weaver ants plus 'soft' chemicals (0.2%, table 4a). However, in this year there was a significant difference among replicates ($p = 0.02$), but the interaction between treatments and replicates was not significant ($p = 0.09$).

In orchard C in both years, fruits were significantly less damaged by the red-banded thrips in the treatments with weaver ants only or with weaver ants plus 'soft' chemicals than in the treatment without weaver ants or soft chemicals (table 4b).

3.4. Laboratory trials

In the 2001 trial with cashew seedlings, the number of nymphs transplanted on seedlings at the beginning was similar between two groups of seedlings (20 August, table 5). In the first 2 weeks of the trial, the majority of nymphs became pupae and emerged as adults. The number of nymphs was similar between the two groups of seedlings, but adult numbers were much higher on the seedlings without weaver ants than with weaver ants (27 August and 5 September, table 5). Starting from 10 September, nymphs started to hatch from eggs, and thrips generations started to overlap from 28 September. During the period between 10 September and 12 October, nymph and adult numbers were significantly higher on seedlings without weaver ants than with weaver ants (table 5). Starting from the third week of this trial, the mean number of thrips per seedling was well below 250 individuals on seedlings with weaver ants, while on seedlings without weaver ants, the thrips numbers were always well above 300.

In the first two weeks of the trial the number of healthy and damaged leaves per seedling was not different between the two groups of seedlings (27 August and 5 September, table 5). Starting from week 3 (10 September), healthy leaves were generated each week on seedlings with weaver ants. In contrast, fewer healthy leaves were found on seedlings without weaver ants, and more leaves were damaged each week (table 5). The damaged leaves on seedlings without weaver ants started to fall from week 4 of the trial, and all the leaves on these seedlings had fallen by 12 October (table 5). This difference in the number of leaves fallen in the two groups was highly significant (table 5).

In the 2002 trial with mango seedlings, the initial count of thrips was not different between two groups of seedlings (10 May, table 6). Two weeks later and onwards, the mean number of nymphs and adults per seedling was significantly smaller on seedlings with weaver ants than without the ants (22 May–6 June, table 6). The mean number of the thrips per seedling was under 150 on seedlings with weaver ants, while the thrips on seedlings without the ants exceeded 200, except for 29 May (table 6). By week 4 (6 June), the mean number of healthy leaves per seedling was significantly greater on seedlings with weaver ants than without the ants (table 6). Seedlings with the ants had fewer newly damaged leaves than those without the ants. From the third week of the trial, the damaged leaves on seedlings without the ants started to fall, and more leaves had fallen by the fourth week (table 6). No leaves had fallen from the seedlings with the ants.

4. Discussion

A range of natural enemies of the red-banded thrips has been reported on various tree crops. These include a parasitoid wasp, *Goetheana parvipennis* (Gahan) (Hymenoptera: Eulophidae) on mango (Bennet and Baranowski, 1982), an anthocorid bug, *Orius thripoborus* (Hesse) (Hemiptera: Anthocoridae) on avocado (Dennill, 1992), and three species of Miridae, *Termatophylidea maculata* (Usinger), *T. pilosa* (Reut. & Popp.) and *T. opaca* (Carvalho) on cacao and cashew (Callan, 1975). In the Northern Territory, Young and Chin (1998) mentioned that red-banded thrips were attacked by spiders, lacewings, predatory thrips and predatory bugs. A wasp, *Shakespearia* sp. (Hymenoptera: Encyrtidae) parasitises pupae of the thrips in the Northern Territory (Lanni Zhang, 2003, pers. comm.). The weaver ant has not been reported as a natural enemy of the red-banded thrips.

Table 5. *The effect of* Oecophylla smaragdina *on the development of red-banded thrips on cashew seedlings, at the Charles Darwin University campus, August–October, 2001*

Category	Measurement	Seedlings with	20 Aug.	27 Aug	5 Sep.	10 Sep.	13 Sep.	20 Sep.	28 Sep.	5 Oct.	12 Oct.
Development of thrips	Mean numbers of nymphs/seedling ± SD[1]	*O. smaragdina*	40 ± 17	1 ± 3	3 ± 5	41 ± 43	57 ± 54	83 ± 55	35 ± 7	247 ± 136	89 ± 27
		No ants	38 ± 5	1 ± 1	5 ± 10	309 ± 75	323 ± 26	630 ± 259	262 ± 103	515 ± 303	836 ± 400
		M-W U test [2]	**NS**	**NS**	**NS**	**	**	**	*	**NS**	*
	Mean numbers of adults/seedling ± SD	*O. smaragdina*	0 ± 0	4 ± 5	2 ± 2	2 ± 1	4 ± 3	13 ± 9	22 ± 3	9 ± 5	6 ± 3
		No ants	0 ± 0	21 ± 10	8 ± 6	7 ± 3	9 ± 3	168 ± 42	272 ± 29	46 ± 14	15 ± 19
		M-W U test	**NS**	**	*	**NS**	*	**	*	*	**NS**
Development of seedlings	Mean numbers of healthy leaves/seedling ± SD	*O. smaragdina*	6 ± 2	7 ± 2	12 ± 3	13 ± 3	15 ± 3	17 ± 3	18 ± 3	20 ± 3	21 ± 2
		No ants	7 ± 1	8 ± 2	12 ± 2	8 ± 3	6 ± 4	6 ± 2	4 ± 2	1 ± 1	0.0 ± 0.0
		M-W U test	**NS**	**NS**	**NS**	*	*	**	**	**	*
	Mean numbers of damaged leaves/seedling ± SD	*O. smaragdina*	0	0	0	0	0	1 ± 1	1 ± 2	2 ± 1	2 ± 1
		No ants	0	0	0	3 ± 1	4 ± 1 leaves started falling	5 ± 2 more leaves fallen	5 ± 2 more leaves fallen	4 ± 2 most leaves fallen	All leaves fallen
		M-W U test	**NS**	**NS**	**NS**	**	**	*	*	–	–

[1]Nymphs included pre-pupae and pupae, and SD refers to standard deviation of the mean.

[2]M-W U test refers to Mann-Whitney *U*-test; NS = not significant, * = significant at $p < 0.05$ and ** = significant at $p < 0.01$.

Table 6. *The effect of* Oecophylla smaragdina *on the development of red-banded thrips on mango seedlings, at the Charles Darwin University campus, May–June 2002*

Category	Measurement	Seedlings with	10 May	16 May	22 May	29 May	6 June
Development of thrips	Mean numbers of nymphs/seedling ± SD[1]	*O. smaragdina*	273 ± 156	140 ± 104	1 ± 1	0 ± 0	2 ± 3
		No ants	340 ± 377	398 ± 338	82 ± 34	9 ± 17	280 ± 313
		M-W U test [2]	**NS**	**NS**	**	*	**
	Mean numbers of adults/seedling ± SD	*O. smaragdina*	1 ± 1	9 ± 14	1 ± 1	0 ± 0	0 ± 1
		No ants	3 ± 3	37 ± 41	126 ± 135	16 ± 32	5 ± 8
		M-W U test	**NS**	*	**	**NS**	**
Development of seedlings	Mean numbers of healthy leaves/seedling ± SD	*O. smaragdina*	6 ± 3	6 ± 3	5 ± 4	5 ± 3	7 ± 5
		No ants	9 ± 5	10 ± 6	7 ± 5	6 ± 5	0 ± 0
		M-W U test	**NS**	**NS**	**NS**	**NS**	**
	Mean numbers of newly damaged leaves/seedling ± SD	*O. smaragdina*	3 ± 1	3 ± 1	1 ± 1	0 ± 0	0 ± 0
		No ants	2 ± 2	3 ± 2	5 ± 3	4 ± 2 leaves started falling	6 ± 3 more leaves fallen
		M-W U test	**NS**	**NS**	**	**	**

[1]Nymphs included pre-pupae and pupae, and SD refers to standard deviation of the mean.

[2]M-W U test refers to Mann-Whitney *U*-test; NS = not significant, * = significant at $p < 0.05$ and ** = significant at $p < 0.01$.

Weaver ants are effective in limiting damage to mango leaf shoots by the red-banded thrips. Data from the field surveys in each of three orchards (tables 2–3) were consistent, and demonstrated that trees with abundant weaver ants were significantly less damaged than trees with fewer, or without, weaver ants. Based on the data from eight field surveys in three orchards over the period of four years, the mean damage in trees with abundant weaver ants was 2.8% of the shoots, while 21.1% and 30.3% of the shoots were damaged on trees with fewer weaver ants or without the ants respectively. Damage levels of $< 5\%$ of shoots damaged by red-banded thrips are acceptable to farmers (Les Brigden and Malcolm Green, 2003, pers. comm.).

Weaver ants are effective in reducing thrips numbers. Whether the red-banded thrips populations were high or low in orchards, the number of the thrips per leaf was lowest on trees with abundant weaver ants (table 1). Igboekwe (1985) studied cashew seedlings infested by red-banded thrips and suggested that when the thrips populations built up to 240 thrips per seedling, chemical treatment was necessary, and 240 thrips per seedling appeared to be an economic injury level. In our laboratory trials, cashew and mango seedlings with weaver ants were healthy and no leaves dropped (tables 5–6); the mean number of the thrips per seedling, including nymphs and adults, was well below 250 (tables 5–6). This suggests that weaver ants can limit red-banded thrips populations under the economic injury level for mango and cashew seedlings as that was suggested by Igboekwe (1985).

Weaver ants are effective in protecting mango fruits from red-banded thrips. The proportion of fruits damaged by the thrips in orchard C in each of the two years was much lower on trees with weaver ants than without the ants (table 4). In orchard A in 2001, the proportion of fruits damaged by the red-banded thrips was higher in the treatment with chemical insecticides than in the treatment with weaver ants plus ‘soft’ chemicals (table 4a). In 2002, there was no significant difference of the fruit damage between the two treatments, suggesting that weaver ants are at least as effective as the chemical insecticides used in these trials.

There are two species of weaver ants in the world: *Oecophylla smaragdina* (Fab.) distributed widely in south-east Asian countries, south Pacific islands and northern Australia; and *O. longinoda* (Latreille) distributed in tropical Africa (Cole and Johns, 1948). These species are so similar in their life-histories and ecology that they can be treated as one (Way, 1954, Van der Plank, 1960, Greenslade, 1971a, Holldobler and Wilson, 1983, Peng *et al*., 1998a,b, Way and Khoo, 1992). Mangos grown in the areas of tropical Asia, Australasia and Africa suffer from red-banded thrips damage (Hill, 1975, Pena, *et al*., 2002). Most nations in these areas are developing countries, where insecticides and spray equipment are usually expensive and labour costs are low. Thus, the use of the ants to control red-banded thrips can be both successful and cost-effective.

Compared to other natural enemies of red-banded thrips, weaver ants have the following advantages:

(1) Under natural conditions, weaver ants can significantly reduce red-banded thrips damage in mango orchards (tables 1–3). Weaver ants can also reduce red-banded thrips numbers under the economic injury level on mango and cashew seedlings;
(2) Mango trees are ideal hosts for weaver ants, and the ants are often abundant in unsprayed mango orchards (Majer and Camer-Pesci, 1991). In our field surveys, an average of 47% of mango trees (tables 1–3) had abundant weaver ants. Therefore, it is easy to locate and maintain the ants in mango orchards;
(3) The ants can live on mango trees all year, constantly controlling red-banded thrips populations;
(4) For mango orchards without weaver ants, transplantation of the ants into the orchards is possible. A transplanted ant colony with queen ants can last three or more years in orchards (Peng *et al*., 2000b). By comparison, if other natural enemies such as parasitoid wasps and lacewings are used, a repeated release of the wasps and lacewings at least twice a year is necessary; and
(5) Apart from controlling the red-banded thrips, weaver ants can also control several other main insect pests in mango orchards, such as leafhoppers, leaf-rollers, seed weevils, fruit-spotting bugs, flower caterpillars and fruit-flies (Peng and Christian, unpublished data), but the other natural enemies cannot control this range of pest species.

However, there are several arguments against using the ants in mango orchards. These include the mutual relationship between the ants and mealybugs, the fact that fruit quality can be affected by drops of formic acid secreted by the ants, the aggressive behaviour of the ants and the ant population stability in orchards.

Weaver ants have a close association with some homopterans such as scales, mealybugs and some species of aphids (Way, 1963), and they encourage mealybug populations in mango orchards (Peng and Christian, unpublished data). According to the results of our current research, the mean fruit damage by all insect pests, including caterpillars, thrips, fruit-spotting bugs, seed weevils, fruit-flies and mealybugs, was 10% in trees protected by weaver ants plus ‘soft’ chemicals, in which mealybug damage accounted for 3%. In trees protected by chemical insecticides, 13% of fruits were damaged on average, in which mealybug damage accounted for 0.4% (Peng and Christian, unpublished data). This suggests that mealybug damage on mango fruits resulting from the use of weaver ants is balanced by less damage by other insect pests.

The deposition of weaver ant formic acid can cause black spots on fruit skin. A fruit is downgraded if there are > 10 black spots on it. In our field experiments, 3% of fruits were downgraded due to ant marks (Peng and Christian, unpublished data). If fruits damaged by all insect pests, including ant marks, are considered, 13% of fruits were damaged in trees protected by weaver ants plus ‘soft’ chemicals, while 13% of fruits were also damaged in trees protected by chemical insecticides. This suggests that the damage on mango fruits due to ant marks is compensated by the beneficial effects of the ants.

Aggressive behaviour is well known in weaver ants, and this may disturb people during fruit harvest. Spraying with contact-killing insecticides like Pyrethrum in mango orchards reduces the abundance of weaver ants, but it also reduces ant ability to control pests. During the period of mango harvest in 2001 and 2002, six farmers who are involved in this research did not consider ant aggressiveness a significant problem. To avoid disturbance from the ants, some farmers put fruits directly into a bucket filled with water and mango wash solution for 1 min. This also serves to remove sap from the fruits. Farmers in Vietnam and Gabon sometimes put ash powder on the tree trunk or on main branches when they harvest fruits or temporarily remove ant nests (Van Mele and Cuc, 2003). Based on our observations that weaver ants either went back to their nests or stayed under twigs and leaves when it was raining, a field experiment using seven-year-old mango trees showed that the activity of weaver ants was reduced by 88% for the first 20 min after spraying with water and by 61% for further 30 min (Peng and Christian, unpublished data). Mango fruits and tree leaves dried in 20 min, thus the added water was too little to cause fruit lenticel or post-harvest diseases (Anna Couttie, Les Brigden, Malcolm Green and Lloyd Pierce, 2003, pers. comm.).

Under natural conditions, weaver ant populations are not distributed evenly across trees and months of the year in mango orchards. This distribution affects the control efficiency of red-banded thrips (tables 2 and 3). Population fluxes are related to the fact that weaver ants have strong territorial behaviour. Fierce boundary fights between weaver ant colonies (Peng *et al*., 1999) and between weaver ants and other ant species (Greenslade, 1971b, Majer and Camer-Pesci, 1991, Way and Khoo, 1992, Peng, personal observations) are well documented. To maintain weaver ant populations at high levels to control red-banded thrips in mango orchards, it is advisable to isolate weaver ant colonies from each other, to use ant baits to control other competitive ant species, and to transplant new weaver ant colonies as needed (Way and Khoo, 1992, Peng *et al*., 1999, 2000b).

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