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Weaver Ant Role in Cashew Orchards in Vietnam

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ABSTRACT Cashew (*Anacardium occidentale* L.) is a very important source of income for more than 200,000 farmer households in Vietnam. The present cashew productivity in Vietnam is low and unstable, and pest damage is partly responsible for this. Cashew farmers rely on pesticides to minimize the damage, resulting in adverse impacts on farm environment and farmers' health. Weaver ants (*Oecophylla* spp) are effective biocontrol agents of a range of cashew insect pests in several cashew-growing countries, and these ants are widely distributed in Vietnam. The aim of this study is to evaluate the potential of weaver ants in cashew orchards in Vietnam. Field surveys and field experiment were conducted in five cashew orchards from July 2006 to January 2008 in Binh Phuoc, Dong Nai, and Ba Ria Vung Tau provinces, Vietnam. Based on the field surveys, the most important pests that damage flushing foliar and floral shoots and young cashew fruits and nuts were mosquito bugs, brown shoot borers, blue shoot borers, and fruit-nut borers. The damage caused by each of these pests was significantly lower on trees with weaver ants compared with trees without the ants, showing that the ants were able to keep these pest damages under the control threshold. Regular monitoring of the field experiment showed that weaver ants were similar to insecticides for controlling mosquito bugs, blue shoot borers, fruit-nut borers, leaf rollers, and leaf miners. Aphids did not become major pests in plot with weaver ants. To manage insect pest assemblage in cashew orchards, an integrated pest management using weaver ants as a major component is discussed.

KEY WORDS *Oecophylla smaragdina*, fruit-nut borer, cashew insect pest, mosquito, shoot borer

Cashew (*Anacardium occidentale* L.) is an important crop in Vietnam with the annual export value of USD1 billion (VINACAS 2010). It is a very important source of income for more than 200,000 farmer households (Bien 2005). To improve the national economy, especially in the rural area, the Ministry of Agriculture and Rural Development of Vietnam has designated cashew development as a national priority. The present cashew productivity in Vietnam is low and unstable, which is mainly due to serious damage caused by various pests (Christian et al. 2011).

Cashew was introduced to Vietnam in the 18th century, and it did not become a commercial crop until the 1990s, when the cashew processing industry was developed (Nguyen 2010). The pest assemblage in Vietnamese cashew orchards mainly comprises generalist feeders. More than 40 species of pests were recorded in cashew orchards in Vietnam (Peng et al. 2010a,b). Among these, the most important pests are mosquito bugs (*Helopeltis theivora*), the brown shoot borer (*Alcidodes* sp.), the blue shoot borer (Curculionidea sp.), the fruit-nut borer (*Nephopteryx* sp.), the branch borer (*Rhytidodera bowringii*), the stem-root borer (*Plocaederus obesus*), and anthracnose disease. The former five pests annually cause serious damage on foliar, floral shoots, and young fruits and nuts, resulting in a great reduction of yield and nut quality (Nguyen 2010, Peng et al. 2010a,b).

To minimize the damage, most cashew farmers rely on insecticides and fungicides, resulting in increased costs, pest resistance, the reduction of natural enemies and pollinators, environmental pollution, and a threat to farmers' health and their animals. A farmers' interview conducted by researchers from Charles Darwin University, Australia, and the Institute of Agricultural Science of South Vietnam (Christian et al. 2011) showed that cashew farmers heavily used pesticides to control the main pests during the period of cashew flowering and fruiting. More than 80% of the cashew farmers suffered from various kinds of poison symptoms during or after spraying pesticides in their orchards (Christian et al. 2011). These poison symptoms included skin irritation, headache, vomiting, breathing difficulty, unconsciousness, sneezing, loss of appetite, dizziness, chest pains, and/or tiredness. Some farmers mentioned that their poultry grew slowly and laid eggs irregularly. Their pigs suffered miscarriage and piglets born during a pesticide spray period were weak and had poor health (Christian et al. 2011). In addition to these, 92% of the farmers said that pesticide spray had already caused adverse effects on the farm environment, and this included pollution to water and soil,

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Table 1. Cashew insect pests that are controlled by weaver ants: *Oecophylla smaragdina* being used in Australia, Papua New Guinea, and East Timor, and *O. longinoda* being used in Ghana and Mozambique

Country	Scientific name	Common name	Order/family	References
Australia	*Amblypelta lutescens*	Fruit spotting bug	Hemiptera/Coreidae	Peng et al. 1995, 1997a,b, 1999a, 2004
	Anigraea ochrobasis	Leaf roller	Lepidoptera/Noctuidae	
	Helopeltis pernicialis	Mosquito bug	Hemiptera/Miridae	
	Nezara viridula	Green vegetable bug	Hemiptera/Pentatomidae	
	Penicillaria jocosatrix	Mango tip borer	Lepidoptera/Noctuidae	
East Timor	*Amblypelta lutescens*	Fruit spotting bug	Hemiptera/Coreidae	Amaral 2010
	Helopeltis spp	Mosquito bug	Hemiptera/Miridae	
Papua New Guinea	*Edistus* sp	Leaf beetle	Coleoptera/Chrysomelidae	Peng 1999, 2000
	Amblypelta papuensis	Fruit spotting bug	Hemiptera/Coreidae	
	Penicillaria Jocosatrix	Mango tip borer	Lepidoptera/Noctuidae	
Mozambique	*Helopeltis anacardii*	Mosquito bug	Hemiptera/Miridae	Peng 2002
	Pseudotheraptus wayi	Coconut bug	Hemiptera/Coreidae	
Ghana	*Anoplocnemis curvipes*	Coreid bug	Hemiptera/Coreidae	Dwomoh et al. 2009
	Helopeltis schoutedeni	Mosquito bug	Hemiptera/Miridae	
	Pseudotheraptus devastans	Coreid bug	Hemiptera/Coreidae	

reduction of beneficial insects, and more frequent pest outbreaks (Christian et al. 2011).

To reduce the use of insecticides, cashew farmers are seeking alternative methods to control pests. The use of biological control agents is one of their options. Weaver ants, *Oecophylla smaragdina* (F.) and *Oecophylla longinoda* (Latreille) (Hymenoptera: Formicidae), have been documented as most effective biocontrol agents of a range of insect pests. More than 100 pest species belonging to 8 orders and 26 families on 8 tropical tree crops and 6 forest trees are controlled by *Oecophylla* ants (Peng and Christian 2010). The effectiveness of weaver ants in biological control has been reviewed by Way and Khoo (1992) and Van Mele (2008). Particularly on cashew crops, at least 14 major insect pests are efficiently controlled by weaver ants in several cashew-growing countries (Table 1). A weaver ant technology using weaver ants as a key element has been implemented to control the major insect pests by cashew growers in Australia (Peng et al. 2004), Papua New Guinea (Peng 1999, 2000), East Timor (Amaral 2010), and Mozambique (Peng 2002). Weaver ants, *O. smaragdina*, are widely distributed in tropical areas of south-east Asia and northern Australia (Lokkers 1986), and they are abundant in Vietnam (Van Mele et al. 2002). Weaver ants have been used to control citrus insect pests on the Mekong delta in Vietnam for many years (Van Mele et al. 2002), but the role of the ants in cashew orchards has not been explored. Because the major insect pest groups in Vietnamese cashew orchards are similar to those in Australia and East Timor, it is important to evaluate the impact of the ants on the main cashew insect pests in Vietnam.

To explore the potential of the weaver ant in cashew orchards in Vietnam, we took two approaches: field survey and field experiment. In the field survey, we expect that some trees in cashew orchards that received no or little pesticide spray will be naturally occupied by weaver ants, and these trees will be significantly less damaged by the main pests than trees without the ants. In the field experiment, we expect that cashew orchards that regularly receive insecticide sprays will have no weaver ants, and transplantation of weaver ants will achieve similar or better results in controlling the main pests compared with those trees managed by insecticides.

Materials and Methods

Study Sites. In all, seven field surveys were conducted in four cashew orchards in southern Vietnam in 2006 and 2007 in Binh Phuoc, Dong Nai, and Ba Ria Vung Tau provinces, of which Binh Phuoc and Dong Nai are the biggest cashew-growing provinces in Vietnam. Location and characteristics of each of the four study sites, together with weaver ant status and the number of surveys done for each site, are shown in Table 2. Some additional information about Mr. Quang's and Mr. Be's orchards is provided in the following text. In Mr. Quang's orchard, there were 60 cashew trees (14 big trees and 46 small ones). As big trees were too tall to make an accurate assessment of the pest damage, surveys were concentrated on the 46 small trees. Mr. Be's orchard comprised several blocks of cashews with different ages. The first survey was conducted in a cashew block of 3 ha. In this block, trees were more than 20 yr old, but there were 18 young trees (4 yr old) randomly growing among the big trees due to the replacement of the dead trees. Because big trees were too tall to assess pest damage, the 18 small trees were used in this survey. The second survey was conducted in another cashew block of 1 ha, containing 100 trees of similar size. Every other tree in a row was chosen and 50 trees were used (Table 2).

Sampling Methods. In each survey, all trees listed in Table 2 were inspected, and for each tree, we recorded the total numbers of flushing terminals (including leaf shoots, flower panicles, and/or young fruits and nuts) on the tree, the number of the terminals freshly damaged by each of the main pests, and the dominant ant species on the tree. The dominant ant species referred to the species with the most numbers of individuals compared with the other species of ant in that tree (each tree we surveyed had more than one species of ant). The percentage damage was later calculated for each pest. The fresh damage symptoms by each of the

Table 2. Study site location, orchard size, surrounding habitat, history of pesticide use, the status of weaver ants, and the no. of surveys done in each site

Orchard owner and location	No. of trees used	Tree age and size	Surrounding habitat	Use of pesticide	Weaver ant (WA) status	Time of survey
Mr. Quang, Dong Xoai district, Binh Phuoc province (11° 75′ N, 106° 72′ E)	46	4 yr old, 3.5–5.0 m in height	Two patches of African mahoganies and a cassava crop	Never	Three WA colonies on big cashew and mahogany trees spread to some of the young cashew trees	Three surveys done: July 2006 (leaf flushing), Dec. 2006 (flowering), and April 2007 (fruiting)
Mr. Be, Trang Bom district, Dong Nai province (11° 12′ N, 107° 19′ E)	18	4 yr old, 3.5–5.0 m in height	Big cashew trees	One or two times a year	Some WA colonies on big cashew trees spread to some of the young trees	One survey in July 2006 (leaf flushing)
	50	4 yr old, 4.0–5.5 m in height	Big cashew trees	One or two times a year	A few WA colonies on the big trees spread into the 4-yr-old cashew block	One survey in Aug. 2007 (leaf flushing)
Mr. Sau, Trang Bom district, Dong Nai province	53	9 yr old, 7.5–11.0 m in height	Some *Eucalyptus* trees, a young cashew orchard, and a cassava crop	Never	One WA colony in the orchard, and another two colonies spread from *Eucalyptus* trees to cashew trees	One survey in July 2006 (leaf flushing)
Ms. Lun, Ba Ria Vung Tau province (10° 56′ N, 107° 24′ E)	46	4 yr old, 4.0–5.5 m in height	Various sizes of cashew trees	Stopped spraying in Mar. 2006	Two WA colonies on orchard boundary trees spread into the orchard	One survey in July 2006 (leaf flushing)

pests are determined by following the illustrations by Peng et al. (2010a).

Field Experiment. The field experiment was carried out in Mr. Ty's orchard in Dong Phu district of Binh Phuoc province from November 2006 to January 2008. This orchard had 2 ha of 7-yr-old cashew trees. Half of this orchard (1 ha) was used, and it was equally divided into two plots: insecticide plot with 70 trees and weaver ant plot also with 70 trees. A row of cashew trees was used as a buffer zone around the weaver ant plot. For insect pest control, chemical insecticides were used in the insecticide plot. Five sprays were done during the flowering and fruiting period (November–mid April), and no sprays in other months (May to October). Insecticides used were Sherpa25EC (the active ingredient being Cypermethrin 250 g/liter). Insecticide sprays were conducted by the orchard owner based on his own experience. In the weaver ant plot, only weaver ants were used, and the ants were managed by following the methods provided by Peng and Christian (2005). The other farming activities, such as weeding, pruning, fertilizer application, and/or the use of fungicides, were done the same for the two plots, and were conducted by the orchard owner.

Owing to regular insecticide spray, this orchard had no weaver ants when it was used as our experimental orchard. Weaver ants were introduced into the weaver ant plot in November 2006 (preflowering time) by following the weaver ant transplanting methods provided by Peng and Christian (2005). The ant abundance on each tree between the two plots was regularly monitored. No weaver ants were found in the insecticide plot during the experimental period. The weaver ant abundance in the weaver ant plot was expressed as a percentage per tree by the following method: [the number of the main branches with a weaver ant trail on a tree/the total number of the main branches of the tree] $\times$ 100 (Peng and Christian 2005). Main branches were defined as the branches directly derived from the tree trunk and they pointed toward different sections of the tree canopy. An ant trail was defined as "1" if >10 individual ants were seen on a branch when slightly tapping the branch with a stick, and as "0.5" if one to nine ants were seen. This method has been previously evaluated as effective to assess weaver ant abundance (Van Mele et al. 2007).

The major insect pest damage between the two plots was monitored once every 2 weeks based on fresh damage symptoms (Peng et al. 2010a). Monitoring at this interval avoided recounting the same damaged shoots. Preliminary observations suggested that the main insect pests were more active in the lower tree canopy than in the upper level. Therefore, the monitoring was concentrated on the lower level of the tree canopy. For each tree, we recorded the total number of flushing terminals (flushing leaf shoots, flower panicles, and/or young fruits and nuts) at the lower level around the tree and the number of terminals freshly damaged by each pest. Because the fresh and old damage symptoms caused by leaf rollers and the fruit-nut borer were difficult to determine,

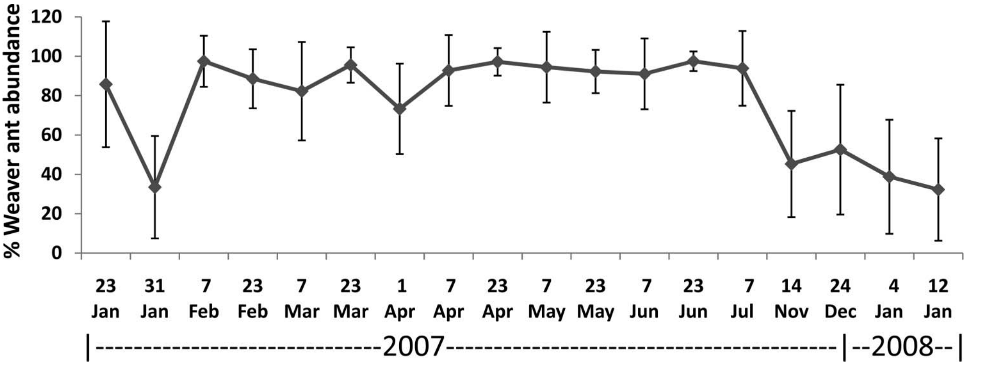

Fig. 1. Average weaver ant abundance in the weaver ant plot at Binh Phuoc province, Vietnam.

one assessment of these two pests during the peak time of their emergence in April 2007 was done.

Data Analysis. Percentage data for each field survey were analyzed separately by using a nonparametric Mann–Whitney *U* test or Kruskal–Wallis one-way analysis of variance (ANOVA) by ranks (Siegel 1956). In our field experiment, the monitoring data from November 2007 to January 2008 were not used because the weaver ant abundance was below 50% (Fig. 1), which was not high enough to control insect pests (Peng and Christian 2005). The monitoring data from December 2006 to September 2007 were divided into two groups based on insecticide spray regimen: group 1 data being from December 2006 to April 2007 (flowering and fruiting) when insecticides were used in the insecticide plot, and group 2 data being from May 2007 to September 2007 (tree dormancy or leaf flushing) when insecticides were not used in the insecticide plot. Each group data were analyzed separately. First we compared the percentage damage per tree for each insect pest between the two plots using the Mann–Whitney *U* test for each monitoring occasion. If there was a significant difference between the two plots, the calculated mean percentage in each plot was used. If there was no significant difference between the two plots, the calculated mean percentage of the two plots was used for both plots. Second, we compared these mean percentage data per monitoring occasion for each insect pest between the two plots using the Friedman two-way ANOVA by ranks (Siegel 1956). SYSTAT statistics software was used.

Results

Field Survey. *Mr. Quang's Orchard.* Based on the damage level of flushing terminals, the main pests in this orchard were the blue shoot borer (Curculionidae sp1.), the mosquito bug (*H. theivora*), the fruit-nut borer (*Nephopteryx* sp.) and leaf rollers (a group of lepidopteran pests including three unidentified species belonging to Gracillaridae sp1, Tortricidae sp1 and Pyralidae sp1; Table 3). The average damage level by these pests ranged between 0.3 and 8.6% on trees with weaver ants, but between 3.4 and 36.0% on trees

Table 3. The mean % flushing terminals (including flushing leaf shoots, flower panicles, and/or young fruits and nuts) damaged by the main insect pests in trees with weaver ants (WA) and trees without the ants (no WA) at Mr. Thiem Truong Quang's orchard, Dong Xoai, Binh Phuoc province, Vietnam

Date	Pest name	Trees with	No. of trees	Mean % (damage/tree ± SD)	Mann–Whitney *U* test	
					Rank sum	Statistic
July 2006	Blue shoot borers	No WA	29	36.0 ± 20.3	890.5	U = 455.5; df = 1; $P < 0.001$
		WA	17	4.6 ± 8.9	190.5	
	Mosquito bugs	No WA	29	8.0 ± 7.6	813.0	U = 378.0; df = 1; $P = 0.002$
		WA	17	2.2 ± 3.7	268.0	
Dec. 2006	Blue shoot borers	No WA	12	6.5 ± 7.0	358.5	U = 280.5; df = 1; $P = 0.025$
		WA	33	2.3 ± 3.4	676.5	
	Mosquito bugs	No WA	12	3.4 ± 4.2	375.5	U = 297.5; df = 1; $P = 0.001$
		WA	33	0.3 ± 1.1	659.5	
April 2007	Blue shoot borers	No WA	19	18.2 ± 15.7	532.0	U = 342.0; df = 1; $P = 0.013$
		WA	25	8.6 ± 12.0	458.0	
	Mosquito bugs	No WA	19	17.0 ± 21.6	522.0	U = 332.0; df = 1; $P = 0.008$
		WA	25	2.5 ± 6.8	468.0	
	Leaf rollers[a]	No WA	19	16.5 ± 18.6	527.0	U = 337.0; df = 1; $P = 0.014$
		WA	25	5.3 ± 8.7	463.0	
	Fruit-nut borers	No WA	9	16.4 ± 20.6	145.0	U = 100.0; df = 1; $P = 0.016$
		WA	15	0.8 ± 2.6	155.0	

[a] Leaf rollers included three unidentified lepidopteran species belonging to Gracillaridae, Tortricidae, and Noctuidae, but their damage symptoms on flushing terminals were similar.

Table 4. The mean % flushing terminals damaged by the main insect pests in trees with weaver ants (WA) and trees without the ants (no WA) or with other species of ant at Mr. Be's orchard, Dong Nai province, Vietnam

Date	Pest name	Trees with	No. of trees	Mean % (damage/tree ± SD)	Mann–Whitney *U* test or Kruskal–Wallis test	
					Rank sum	Statistic
July 2006	Brown shoot borers	No WA	10	26.2 ± 14.0	134.0	U = 79.0; df = 1; $P < 0.001$
		WA	8	0.9 ± 1.4	37.0	
	Mosquito bugs	No WA	10	24.3 ± 17.2	129.0	U = 74.0; df = 1; $P = 0.002$
		WA	8	1.4 ± 2.6	42.0	
Aug. 2007	The coreid bug	WA	15	4.3 ± 4.0	154.0	H = 24.175; df = 4; $P < 0.001$
		Tapinoma melanocephalum	10	25.7 ± 13.2	332.0	
		No ant	13	23.3 ± 10.0	410.0	
		Crematogaster sp.	4	19.6 ± 8.3	107.0	
		Paratrechina sp.	8	26.0 ± 13.2	272.0	

without the ants (Table 3). This difference for each of the pests at the different survey occasions was highly significant (Table 3).

Mr. Be's Orchard. The main pests in this orchard were the brown shoot borer (*Alcidodes* sp.), the mosquito bug (*H. theivora*), and coreid bugs (Coreidea sp.). For each of these pests in each survey, the mean damage level of flushing terminals was significantly lower on trees with weaver ants (<5%) than on trees without weaver ants or with other species of ants (>19%; Table 4).

Mr. Sau's Orchard. The major pests in this orchard were the brown shoot borer (*Alcidodes* sp.), the mosquito bug (*H. theivora*), and the branch borer (*Rhytidodera integra*). Because branch borers damaged mature twigs and branches and they did not cause direct damage on flushing terminals, this pest damage was not assessed in this survey. The average damage of flushing terminals on trees with weaver ants by brown shoot borers and mosquito bugs was 2.4% and 1.4%, respectively (Table 5). These damages were significantly lower than those on trees without weaver ants for each of the two pests (Table 5).

Ms. Lun's Orchard. The main pests in this orchard were the brown shoot borer (*Alcidodes* sp.), the mosquito bug (*H. theivora*), the leaf miner (*Acrocercops syngramma*), and leaf rollers (a group of unidentified lepidopteran species belonging to Gracillaridae sp1, Tortricidae sp1, and Noctuidae sp1). No flushing shoots were damaged by brown shoot borers and mosquito bugs on trees with weaver ants, but the mean damage caused by these two pests was from 5.2% to 27% on trees with *Crematogaster* ants or no ants (Table 5). The average damage caused by the leaf miner and leaf rollers was lower on trees with weaver ants (2.9 and 2.5%) than on trees with *Crematogaster* ants (12.7 and 7.9%) or without ants (12 and 8.7%). However, these differences were not significant (Table 5).

Field Experiment. Weaver ant populations in the weaver ant plot were high and stable from January to July 2007, and the average ant abundance was >80% (Fig. 1). However, from October 2007 to January 2008, the ant populations gradually decreased from 60 to 30% (Fig. 1).

Based on the regular monitoring throughout a year, the main insect pests in this orchard were the

Table 5. The mean % flushing shoots damaged by the main insect pests in trees with weaver ants (WA) and trees without the ants (no WA) or with other ant species at two sites, July 2006, Vietnam

Site	Pest name	Trees with	No. of trees	Mean % (damage/tree ± SD)	Mann–Whitney *U* test or kruskal–wallis test	
					Rank sum	Statistic
Mr. Sau's orchard, Dong Nai province	Brown shoot borers	No WA	45	8.3 ± 8.2	1,321.0	U = 286.0; df = 1; $P = 0.008$
		WA	8	2.4 ± 3.8	110.0	
	Mosquito bugs	No WA	45	5.5 ± 4.7	1,337.0	U = 302.0; df = 1; $P = 0.002$
		WA	8	1.4 ± 2.8	94.0	
Ms. Lun's orchard, Ba Ria Vung Tau province	Brown shoot borers	WA	3	0.0 ± 0.0	18.0	H = 13.715, df = 2, $P = 0.001$
		Crematogaster sp.	28	13.0 ± 2.4	573.0	
		No ants	15	27.0 ± 4.3	490.0	
	Mosquito bug	WA	3	0.0 ± 0.0	25.5	H = 5.903, df = 2, $P = 0.052$
		Crematogaster sp.	28	5.2 ± 1.1	633.5	
		No ants	15	8.6 ± 2.1	422.0	
	Leaf miner	WA	3	2.9 ± 1.8	32.0	H = 3.258, df = 2, $P = 0.196$
		Crematogaster sp.	28	12.7 ± 2.0	706.0	
		No ants	15	12.0 ± 3.1	343.0	
	Leaf rollers[a]	WA	3	2.5 ± 2.5	41.0	H = 1.718, df = 2, $P = 0.410$
		Crematogaster sp.	28	7.9 ± 1.4	673.5	
		No ants	15	8.7 ± 2.3	366.5	

[a] Leaf rollers included three unidentified lepidopteran species belonging to Gracillaridae, Tortricidae, and Noctuidae, but their damage symptoms on flushing terminals were similar.

Table 6. The mean % flushing terminals (including flushing leaf shoots and flower panicles) damaged by insect pests in the weaver ant plot (WA) and the insecticide plot (insecticide) in Mr. Ty's orchard at Binh Phuoc province, Vietnam

Tree phenology	Pest name	Treatment	Mean % shoots (damaged/tree ± SD)	Friedman two-way ANOVA	
				Rank sum	Statistic
Flowering and fruiting period (insecticides were used in the insecticide plot)	Mosquito bugs	Insecticide	9.2 ± 2.7	14.0	X_r^2 = 2.000; df = 1; P = 0.157
		WA	6.1 ± 0.8	10.0	
	Blue shoot borers	Insecticide	9.3 ± 2.1	13.0	X_r^2 = 0.500; df = 1; P = 0.480
		WA	7.0 ± 1.5	11.0	
	Leaf miners	Insecticide	2.2 ± 0.6	13.0	X_r^2 = 0.500; df = 1; P = 0.480
		WA	1.9 ± 0.5	11.0	
	Aphids	Insecticide	12.6 ± 3.9	12.5	X_r^2 = 0.143; df = 1; P = 0.705
		WA	11.2 ± 4.0	11.5	
Dormancy or leaf flush period (insecticides were not used in the insecticide plot)	Mosquito bugs	No insecticide	6.5 ± 11.2	16.0	X_r^2 = 8.000; df = 1; P = 0.005
		WA	2.4 ± 4.3	8.0	
	Blue shoot borers	No insecticide	5.0 ± 2.0	16.0	X_r^2 = 8.000; df = 1; P = 0.005
		WA	2.4 ± 0.9	8.0	
	The leaf miner	No insecticide	1.2 ± 1.0	15.0	X_r^2 = 4.500; df = 1; P = 0.034
		WA	0.5 ± 0.3	9.0	
	Aphids	No insecticide	9.0 ± 5.9	8.0	X_r^2 = 8.000; df = 1; P = 0.005
		WA	13.3 ± 9.6	16.0	

mosquito bug (*H. theivora*), the blue shoot borer (Curculionidae sp.), the fruit-nut borer (*Nephopteryx* sp.), and leaf rollers (a group of lepidopteran pests including four unidentified species belonging to Gracillaridae sp1, Tortricidae sp1, Pyralidae sp1, and Noctuidae sp1; Tables 6 and 7). The leaf miner (*Acrocercops syngramma*) and the aphids (*Aphis gossypii*) are minor pests (Table 6). The branch borer (*R. integra*) was common, although its damage was not assessed.

During the period of flowering and fruiting (December to April), the average level of cashew flushing shoots and/or flowers damaged by mosquito bugs, blue shoot borers, leaf miners, or aphids was similar between the two plots (Table 6). The average level of developmental nuts and fruits damaged by the fruit-nut borer was significantly lower in the weaver ant plot than in the insecticide plot (Table 7), but the damage caused by leaf rollers was similar between the two plots (Table 7).

During the dormancy or leaf flush period (May to September), the damage on flushing shoots by mosquito bugs, blue shoot borers, and leaf miners was significantly lower in the weaver ant plot than in the insecticide plot (Table 6). However, the average level of shoots with aphids was higher in the weaver ant plot than in the insecticide plot (Table 6).

Discussion

Although our field experiment lacked a replicate, the results obtained by a regular monitoring together with the utilization of Mann–Whitney *U* test and the Friedman two-way ANOVA by ranks should be adequate for interpreting the difference of insect pest damage between the two treatments.

Based on field surveys and the field experiment, the most important insect pests that damaged flushing foliar and floral terminals were the mosquito bug, the brown shoot borer, the blue shoot borer, and the apple-nut borer. The coreid bug and leaf rollers were less important, and the leaf miner and the aphids were minor pests. Apart from the blue shoot borer that mainly occurred in the Binh Phuoc province, the other pests widely distributed in many other cashew-growing areas in Vietnam. The branch borer was commonly found in most cashew-growing areas.

Weaver ants are effective in controlling several major insect pests. The results from our seven field surveys were consistent with the four different types of orchards and with different cashew phenological periods. Flushing terminals were significantly less damaged by the mosquito bug, the brown shoot borer, the apple-nut borer, and coreid bugs on trees with weaver ants compared with trees without the ants (Tables 3–5). Peng et al. (1997a) demonstrated that the con-

Table 7. The mean % flushing terminals (flushing leaf shoots for leaf rollers and developing fruits and nuts for fruit-nut borers) damaged by insect pests in the weaver ant plot (WA) and the insecticide plot (insecticide), April 2007, in Mr. Ty's orchard at Binh Phuoc province, Vietnam

Pest name	Treatment	No. of trees	Mean % (damage/tree ± SD)	Mann–Whitney *U* test	
				Rank sum	Statistic
Fruit-nut borers	Insecticide	28	27.1 ± 4.6	1094.5	U = 688.500; df = 1; $P < 0.001$
	WA	30	3.3 ± 1.1	616.5	
Leaf rollers[a]	Insecticide	54	25.2 ± 3.0	3358.0	U = 1313.000; df = 1; P = 0.107
	WA	59	18.3 ± 1.9	3083.0	

[a] Leaf rollers included four unidentified lepidopteran species belonging to Gracillaridae, Pyralidae, Tortricidae, and Noctuidae, but their damage symptoms on flushing terminals were similar.

trol threshold for mosquito bugs is 6–10% of flushing shoots freshly damaged. In this study, our assessment of mosquito bug damage on trees with weaver ants was from 0.3 to 6.1% (Tables 3–6), which is within the control threshold of this pest. According to Sub-Departments of Plant Protection in Binh Phuoc and Dong Nai provinces, Vietnam, the control threshold is 5% for the brown shoot borer and 10% for leaf rollers or leaf miners (Nguyen 2010). In this study, we found that on trees with weaver ants, the average damage for the brown shoot borer ranged from 0.9 to 2.4% (Tables 4 and 5), from 2.5 to 5.3% for leaf rollers (Tables 3 and 5), and from 0.5 to 2.9% for the leaf miner (Tables 5 and 6), and these damage levels were lower than the control threshold determined by the Vietnamese government. It is clear that weaver ants are able to keep these pest damages under the control threshold. Although no control threshold is available for the blue shoot borer, the coreid bug, and the fruit-nut borer, this study shows that on trees with weaver ants, the average damage was between 2.3 and 8.6% for the blue shoot borer, 4.3% for the coreid bug, and <3.5% for the fruit-nut borer (Tables 3, 4, 6, and 7), indicating that the ants were effective in controlling these three pests. In our field experiment, during the flowering and fruiting period, weaver ants were similar to insecticides for controlling the mosquito bug, the blue shoot borer, leaf rollers, the leaf miner, and the aphids (Table 6), and the ants were better than insecticides in controlling the fruit-nut borer (Table 7). When no insecticides were used during the period of tree dormancy or leaf flushing, weaver ants provided better protection in the weaver ant plot than in the insecticide plot for controlling mosquito bugs, blue shoot borers, and leaf miners (Table 6).

The effectiveness of weaver ants on the main cashew insect pests determined in this study agree with studies done by Amaral (2010), Dwomoh et al. (2009), Nguyen (2010), and Peng et al. (1995, 1997a,b, 1999a, 2004). Field experiments conducted by Nguyen (2010) in Vietnam demonstrated that weaver ants effectively controlled the main insect pests on cashew, including the mosquito bug, the brown shoot borer, leaf rollers, and the leaf miner, and they reduced the pest damage either to an acceptable level compared with the insecticide treatment or to levels under the control threshold. In his field experiment in East Timor, Amaral (2010) found that trees protected by weaver ants were significantly less damaged by mosquito bugs and the fruit spotting bug (Coreidae) compared with trees with no protection. Dwomoh et al. (2009) reported that mosquito bug damage was under the control threshold of 6% in both trees occupied by weaver ants and trees treated with insecticides in cashew orchards in Ghana. Peng et al. (1995, 1997a,b, 1999a, 2004) found that weaver ants effectively control the tea mosquito bug, the fruit spotting bug, the mango tip borer, and the leaf roller in cashew plantations in Australia.

Minor pests like aphids are unlikely to become the main pests after weaver ants are used in cashew orchards. Weaver ants have a mutual relationship with some homopteran pests, such as aphids, mealy bugs, and scales. This is because these pests produce sugar in their excreta, which is desirable food for weaver ants. To get a rich sugar solution, weaver ants farm these insects. Therefore, there is a major concern about whether aphids and mealy bugs, which are currently considered as minor pests in cashew orchards, will become major ones after the main pests are controlled by weaver ants. Based on our regular monitoring, the average level of flushing terminals with aphids was similar between the two plots during the flowering and fruiting period (Table 6). With their field experiments and laboratory rearing, Nguyen (2010) and Peng et al. (2010a,b) found that at least 10 species of natural enemies of aphids or mealy bugs are recorded in cashew orchards, and these natural enemy populations are higher in orchards with weaver ants than in orchards sprayed with insecticides. However, during the period of tree dormancy or leaf flushing, trees in the weaver ant plot had 4% more shoots with aphids than the insecticide plot (Table 6). During this period, trees had much lower numbers of flush shoots than the flowering and fruiting period, and these terminals were intensively patrolled by weaver ants to get enough food, especially shoots with aphids. This way, aphids are better protected by the ants, and the natural enemy activity was reduced in the weaver ant plot, resulting in relatively high levels of shoots with aphids in the weaver ant plot (Table 6). In contrast, during this period, the insecticide plot received no insecticide sprays, and natural enemy populations recovered, resulting in lower numbers of shoots with aphids compared with the weaver ant plot (Table 6). Here, we should mention that during this time of year, aphids cannot do much damage to trees and should not have an effect on cashew yield in the following year. Instead, they provide food for weaver ants, keeping the ant populations high and stable, which in turn keep the main insect pest populations at the low level during the crop season. Furthermore, in our seven field surveys in this study, we found that on trees with weaver ants, aphids or mealy bugs were present, but their populations were too low to warrant a meaningful assessment. Field experiments conducted in a cashew plantation in plots with weaver ants and plots without the ants or insecticides in the Northern Territory, Australia, over a period of 5 yr by Peng, et al. (1999b) demonstrated that the populations of mealy bugs, aphids, and scales were too low to measure, and that weaver ants have no impact on the predators and parasitoids of mealy bugs, aphids, and oriental scales.

Although weaver ants are effective in controlling several main insect pests, other methods are still needed to manage pest assemblage in cashew orchards. Peng et al. (2010a,b) demonstrate that weaver ants cannot exert their predatory influence on branch borers, stem-root borers, and thrips, which are also economically important. The larvae of branch borers feed inside mature branches, often resulting in the death of production branches in tree canopy (Peng et al. 2010b). The larvae of stem-root borers (*P. obesus*) feed inside tree trunk and main roots of old cashew trees (>15 yr old), resulting in the death of major trunks or even the whole tree (Chau 2006, Peng et al. 2010a). Thrips damage young fruits and nuts, resulting in reduction of yield and poor nut quality (Peng et al. 2004, 2010a,b). When weaver ants are used in cashew orchards, common insecticides such as Cypermethrin, Permethrin, Fenvalerate, Dimethoate, Carbaryl, Trichlorfon, Methidathion, Fenobucarb, and Fipronil recommended to use for controlling these pests (L.P.L., unpublished data) cannot be used because the ants are very susceptible to these insecticides. Having extensively worked on these issues, an integrated pest management using weaver ants as a major component (IPM-Ant) has been developed by Peng et al. (2010a,b). The IPM-Ant was tested by Nguyen (2010), who showed that the IPM-Ant increases a net profit of at least 13% for cashew farmers in addition to significant increases in cashew nut quality and in arthropod diversity and natural enemy populations in orchards.

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