Research reports

The effect of non-crop vegetation on the insect pests and their natural enemies in cashew (*Anacardium occidentale* L.) plantations

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Abstract
In order to introduce an integrated pest management program in cashews, the effect of non-crop vegetation on the arthropod fauna in cashew plantations in tropical northern Australia was studied by taking regular vacuum samples. Where cashews had rich understorey and were closely surrounded by non-crop vegetation, the diversity of arthropods, the ratio of the total natural enemy numbers to insect pests and the average yield were significantly higher than where cashew trees had no understorey and were isolated from non-crop vegetation. We suggest that the close proximity of non-crop vegetation enriches the diversity of arthopods in cashew plantations by providing a reservoir of natural enemies that naturally regulate insect pests and results in an increased crop yield.

Introduction
Pilot cashew plantations in the Northern Territory of Australia have been subject to serious insect pest problems since 1988 (Houston and Malipatil 1991, Peng *et al.* 1995, Stonedahl *et al.* 1995). Consequently, insecticides have to be regularly used to control insect pests such as *Helopeltis pernicialis* (Stonedahl, Malipatil and Houston), *Amblypelta lutescens* (Distant) and *Penicillaria jocosatrix* (Guenee). Insecticides can lead to a reduction in insect pest parasite and predator populations as well as insect pollinator populations. It is therefore very important to explore alternative control methods.

Cashew plantations in the Northern Territory of Australia are surrounded by non-crop vegetation such as *Acacia*, *Eucalyptus*, *Erythrophleums*, *Planchonia* and *Buchanania*. The 'natural enemy hypothesis' predicts that there will be a greater abundance and diversity of natural enemies of pest insects in polycultures compared to monocultures (Root 1973). We wished to determine whether the presence of non-crop vegetation near cashew trees could provide a reservoir of natural enemies that may regulate insect pests in cashew plantations. The most important predators of the main cashew insect pests are green ants, *Oecophylla smaragdina* (Fabricius) (Peng *et al.* 1995). The specific aims of this study were:

i. to assess whether proximity to non-crop vegetation can increase the diversity of arthropods,
ii. to determine whether non-crop vegetation can enhance natural enemy populations in cashew plantations, especially the green ant population and
iii. to determine whether there is a relationship between the proximity of non-crop vegetation and crop yield.

Materials and methods

Study sites
Two study sites were used for this study: a two hectare section of eight-year-old cashew trees at the Wildman River Plantation (12° 64'S, 131° 87'E) and a two hectare stand of six-year-old cashew trees at the Howard Springs Farm (12° 49'S, 131° 04'E). The Wildman River site is 90 km east of Howard Springs. The planting patterns of cashew trees at both sites were similar, and both sites experienced the same tropical wet-dry climate. The study site at Wildman River was in the centre of 16 hectare of cashews (370 m away from non-crop vegetation) and had not received pesticides since June 1993. The study site at Howard Springs had not received pesticides since April 1993 and was closely surrounded by non-crop vegetation. At the Wildman River site, ground vegetation under cashew trees was sparse, containing only a small amount of grass *Pennisetum polystachion* (L.) Schultes between weeding periods. At the Howard Springs site, the ground vegetation was dense and rich, dominated by *P. polystachion*, *Sida* spp., *Calopogonium mucunoides* (Desv.), *Passiflora foetida* (L.) and *Hyptis sauveolens* (L.) Poit.

Sampling method
Samples were obtained using a Ryobi Sweeper Vac (model RSV1100A MKII) vacuum sampler modified according to Wright and Steward (1992). An empty sampling bag was placed in the vacuum sampler before each sample was taken. Ten samples at each site were taken at monthly intervals from September 1993 to October 1994 by applying the vacuum sampler to 30 flushing shoots from each of five cashew trees at the middle level of the tree canopy. At each sampling occasion, a total of fifty evenly distributed trees were sampled at each site. The samples were then frozen. After 24 hours, all the arthropods in each bag were transferred into a bottle containing 70% ethanol for later examination.

Trophic studies
A flexible netting bag (45 × 28 × 18 cm) was used to confine insects to an area on flushing shoots of a field cashew tree to determine the food habits of a variety of arthropod species under realistic conditions. With this technique we could check the bag easily and transfer it to fresh flushing shoots when the condition of the flushing shoots inside the bag became poor due to insect feeding. This system was used in four cashew phenological periods; pre-flowering (March–April), flowering (May–June), flowering and fruiting (June–August) and ordinary flush (September–October) from September 1993 to August 1995. To determine the relationship between insect pests and their predatory arthropods, each predatory species together with each species of insect pest was introduced into the bag which covered two arthropod free flushing shoots. These bags were checked once a day for two days. Eight field observations were made to observe the feeding behaviour of the main insect pests and their natural enemies during the insect pest outbreak of 1994 and 1995. Observations were made during three periods (early morning, noon and early evening) and each period lasted 1–1.5 hours.

Arthropod identification
Known cashew insect pests and their natural enemies were identified to species. Other arthropods were identified to species, genera, sub-family or family level.

Yield assessment
To harvest cashews, growers wait for the nuts to drop on the ground before they are picked up by a vacuum harvester. Eight trees at each site were randomly chosen for yield assessment. At the beginning of the fruit setting period, fallen leaves, twigs and grass under each tree were cleared to facilitate a late harvest. All the nuts under each tree were collected by the vacuum harvester and weighed separately.

Climatic data
The microclimatic data at the Wildman River Plantation were taken from the records of a meteorological station inside the cashew plantation. The microclimatic data at the Howard Springs site were from the records of the meteorological station of Howard Springs Nature Park, 5 km from the study site.

Statistical analysis
All the arthropods caught by the vacuum sampler were included in the statistical comparisons. The log-series index (α) (Fisher *et al.* 1943) was used for the analysis of diversity: $S = \alpha \ln(1 + N/\alpha)$, where S = number of taxa and N = number of individuals. The greater the value of α, the more diverse is the community. The Jaccard equation, $C_J = j/(a+b-j)$, was used to measure similarity between non-crop trees, insect pests and their natural enemies between the two sites, where j = the number of species in common at both sites, a or b = the number of species which occurred at each site (Southwood 1978). The value of C_J ranges from 0–1, and the bigger the value, the more similar the two sites. The ratio data of natural enemies to pests were transformed to arcsine square root, and the rainfall data were transformed to natural logarithm before statistical tests were applied. Paired sample t tests were used to compare the arthropod diversity, the ratio of natural enemies to insect pests and the microclimatic factors between the two study sites. A group sample t test was used to compare the yields of the two sites.

Results

Similarity of biological and physical factors between two sites
The numbers of non-crop tree species present between the two sites were statistically equivalent (C_J = 0.76, Table 1), and the fauna of the main insect pests and natural enemies in cashew plantations was also equivalent (C_J = 1 and 0.88 respectively, Table 1). Although the mean temperature, the relative humidity and the rainfall were higher at the Howard Springs site than at the Wildman River Plantation, there were no statistically significant differences between the two sites (Table 2).

Arthropod diversity between two sites
A total of 12 800 arthropods was caught, belonging to 348 taxa. These included 206 named species or genera, 131 recognisable taxonomic units under sub-families or families, three at the sub-family level and eight at the family level. There were 11 main species of insect pest and 24 species of natural enemy (Table 3).

The diversity of arthropods between the two sites over one year was compared for each month (Figure 1). For each month, the diversity of arthropods at Howard Springs was significantly greater (P = 0.002) than at Wildman River except for October 1994, in which the diversity at Wildman River was higher than at Howard Springs (Figure 1).

Table 1. Similarity measurement of the richness of non-crop trees close to cashew plantations, the main insect pests and their natural enemies in cashew plantations between Wildman River Plantation (WRP) and Howard Springs (HS).

Type	Number of species WRP	Number of species HS	Number of species in common between two sites	C_J
Non-crop trees	24	27	22	0.76
Insect pests	11	11	11	1.00
Natural enemies	21	24	21	0.88

Table 2. Comparisons of the mean temperature, the mean relative humidity and the rainfall between Wildman River Plantation (WRP) and Howard Springs (HS) from October 1993 to October 1994 using paired sample t tests.

Type	Site	Mean ± SEM	Difference between means ± SDD	t	P
Ave. temperature (°C)	WRP	26.7 ± 0.8	-0.277 ± 0.559	-1.788	0.101
	HS	27.0 ± 0.7			
Ave. relative humidity (%)	WRP	66.8 ± 2.9	-1.000 ± 2.582	-1.396	0.188
	HS	67.8 ± 2.9			
Rainfall (mm)	WRP	94.8 ± 31.8	-0.705 ± 1.273	-1.662	0.135
	HS	146.2 ± 57.9			

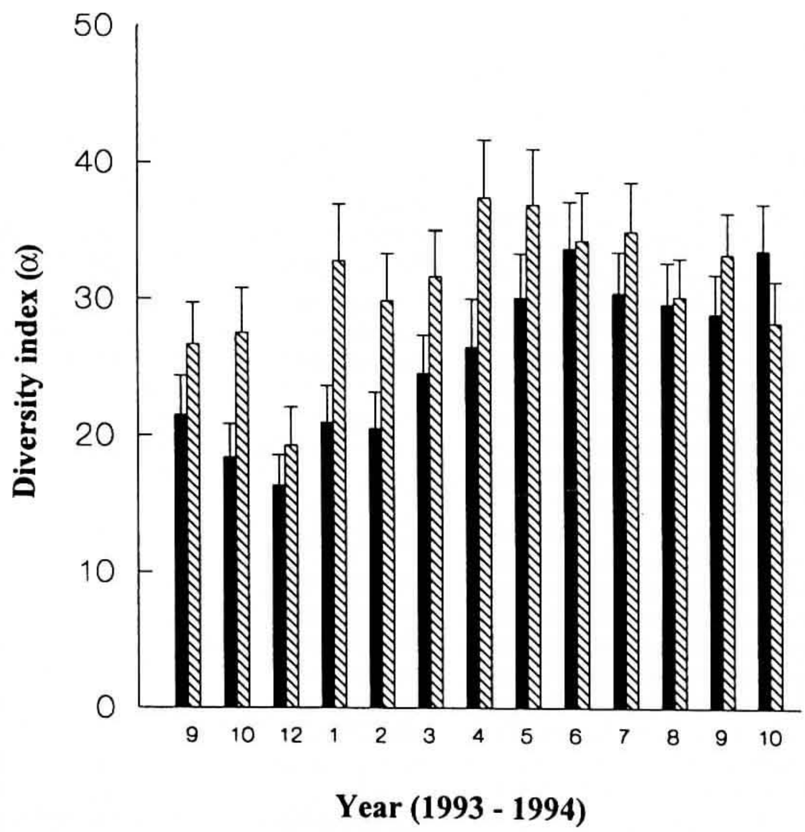

Figure 1. Diversity (log-series index with standard deviation bars) of arthropods on cashew trees between Wildman River Plantation (■) and Howard Springs (▨) for each month.

Insect pests and their natural enemies at the two sites
Table 3 lists the number of individuals of each of the main insect pest species and their natural enemies caught at the two sites. The same 11 species of insect pest occurred at both sites, but the numbers of individuals were higher at Wildman River

than at Howard Springs, except for aphids and flatids which were more numerous at Howard Springs. A greater number of species of natural enemies was caught at Howard Springs (total = 24) than at Wildman River (total = 21), and 13 of the 21 natural enemy species common to both sites were more abundant at Howard Springs than at Wildman River (Table 3).

The numbers of individuals of all insect pest species and their natural enemy species caught at both sites are shown for each month in Table 4. The ratio of natural enemies to insect pests was significantly higher at Howard Springs than at Wildman River ($P = 0.0001$).

Table 5 shows the abundance of *O. smaragdina*. In each month, *O. smaragdina* were much more abundant at Howard Springs than at Wildman River. It took over 15 months after the final pesticide application at the Wildman River site before *O. smaragdina* became common (Table 5).

Yield between two sites

Comparison of the yield for 1993 and 1994 showed that the average yield per tree at Howard Springs was significantly higher ($P = 0.008$ in 1993 and $P = 0.001$ in 1994) than at Wildman River (Table 6).

Discussion

Weather, shelter, host and food have been observed to influence insect diversity (Southwood 1978). The biological and physical factors were not significantly different between the two sites (Tables 1 and 2). Therefore, the difference in arthropod diversity (Figure 1) between the two sites cannot be related to the location and climate. It seems likely that the understorey of cashew trees and close contact between non-crop vegetation and cashews were responsible for the difference. At the Howard Springs site, the understorey which was dominated by five species was very dense between tree rows, and the cashews were closely surrounded by non-crop vegetation composed of 32 tree species. This provided a wide range of hosts, a variety of food and favourable sanctuaries for arthropods. At Wildman River, however, there were almost no weed species and between weeding periods only a small amount of grass was observed, and the closest non-crop vegetation was 370 m away from the experimental cashew trees. This monoculture of cashews provided poor alternative food sources and hosts for the arthropod community.

The farming practice of cashews can be regarded as mono-cropping at Wildman River, but not at Howard Springs. Due to the availability of alternative hosts, food sources and sanctuaries, natural enemies were more abundant than insect pests each month at the Howard Springs site (Table 4). However, at the Wildman River site where alternative hosts and food

Table 3. Abundance of main insect pests (IP) and their natural enemies (NE) collected from cashew trees by a vacuum sampler at Wildman River Plantation (WRP) and at Howard Springs (HS) from September 1993 to December 1994.

Species	Status	Total number trapped at		Feeding habit determined by flexible net bags and field observations
		WRP	HS	
Araneae				
Oxyopidae				
Oxyopes sp.	NE	29	177	Feed on *Helopeltis* nymph
Coleoptera				
Coccinellidae				
Coelophora sp.	NE	2	224	Feed on aphids
C. inaequalis	NE	1	12	Feed on aphids
Cryptolaemus mountrouzieri	NE	49	222	Feed on mealybugs
Rhyzobius sp.	NE	0	14	Feed on scales
Scymnus sp.	NE	58	77	Feed on aphids
Diptera				
Syrphidae				
Eristalis sp.	NE	0	16	Feed on aphids
Hemiptera				
Coreidae				
Amblypelta lutescens	IP	41	1	Feed on foliar and floral flushes
Miridae				
Helopeltis pernicialis	IP	215	11	Feed on cashew shoots, flowers, fruits and nuts
Lygaeidae				
Geocoris australis	NE	23	14	Feed on *Helopeltis* bugs and caterpillars
Pentatomidae				
Platynopus turneri	NE	25	1	Feed on caterpillars
Reduviidae sp.	NE	0	11	Feed on *Helopeltis* nymphs
Homoptera				
Aphididae				
Aphis gissypii	IP	155	364	Feed on new shoots, flowers and nuts
Coccidae				
Ceroplastes rubens	IP	47	5	Feed on twigs and mature leaves
Flatidae				
Siphanta patruelis	IP	36	102	Feed on leaf shoots
Pseudococcidae sp.	IP	125	135	Feed on leaf shoots
Hymenoptera				
Encyrtidae				
Encyrtinae sp.	IP	142	42	Parasitize ladybird pupa
Aphilinidae				
Aphelinus sp.	NE	21	8	Parasitize aphids
Chalcididae				
Brachymeria sp.	NE	3	11	Parasitize *Penicillaria* pupa
Ooencyrtus sp.	NE	4	10	Parasitize *Amblypelta* eggs
Tetracneminae sp.	NE	1	12	Parasitize white louse scale
Eulophidae				
Tetrastichinae sp.	NE	10	12	Parasitize tortricid eggs
Formicidae				
Iridomyrmex sanguineus	NE	23	20	Feed on caterpillars
Oecophylla smaragdina	NE	26	545	Feed on pest bugs, beetles and caterpillars
Platygasteridae				
Aphanomerus sp.	NE	1	2	Parasitize flatids
Scelionidae				
Gryon sp.	NE	21	20	Parasitize Amblypelta eggs
Trichogrammatidae sp.	NE	5	9	Parasitize tortricid eggs

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Species	Status	Total number trapped at		Feeding habit determined by flexible net bags and field observations
		WRP	HS	
Lepidoptera				
Geometridae				
Anisozyga pieroides	IP	26	5	Feed on leaves and flowers
Gracillaridae				
Caloptilia panchrista	IP	314	22	Feed on young leaves
Noctuidae				
Penicillaria jocosatrix	IP	101	17	Feed on foliar fluch, flowers, fruits and nuts
Tortricidae				
Adoxyphyes sp.	IP	45	18	Feed on leaf shoots
Neuroptera				
Chrysopidae				
Chrysopa? sp.	NE	28	17	Feed on aphids
Hemerobiidae				
Psychobiella sp.	NE	16	5	Feed on aphids
Mallada innotata	NE	5	2	Feed on mealybugs
Mantodea				
Mantidae				
Orthoderinae	NE	8	10	Feed on *Helpeltis*, *Amblypelta* and moths

Table 4. The total number of cashew insect pests (IP) and their natural enemies (NE), the ratio of the natural enemies to pests and the phenology of cashew trees for each month at Wildman River Plantation and Howard Springs.

Date	Wildman River			Howard Springs			Cashew tree phenology
	NE	IP	Ratio NE/IP	NE	IP	Ratio NE/IP	
09/93	109	71	1.54	173	64	2.70	Fruiting
10/93	95	132	0.72	169	21	8.05	Fruiting
12/93	52	43	1.21	73	13	5.62	Leaf flush
01/94	81	29	2.79	80	7	11.43	Dormancy
02/94	35	21	1.67	107	18	5.94	Leaf flush
03/94	52	144	0.36	200	20	10.00	Dormancy
04/94	24	29	0.83	84	33	2.55	Leaf flush
05/94	70	104	0.67	155	21	7.38	Leaf flush
06/94	91	91	1.00	182	132	1.38	Flowering
07/94	124	235	0.53	172	110	1.56	Flowering
08/94	106	226	0.47	313	311	1.01	Fruiting
09/94	146	253	0.58	396	133	2.98	Fruiting
10/94	115	142	0.81	300	34	8.82	Fruiting

Table 5. The number of samples with *Oecophylla smaragdina* (NSOS) and the total number of individuals of *O. smaragdina* (TNOS) caught in each sampling occasion at Wildman River Plantation (WRP) and Howard Springs (HS) from September 1993 to October 1994. Ten random samples were taken each month at each site.

Site	Type	Year												
		1993			1994									
		Sep	Oct	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
WRP	NSOS	0	0	1	0	0	1	1	0	0	2	1	3	6
	TNOS	0	0	1	0	0	1	1	0	0	2	1	4	16
HS	NSOS	5	6	7	9	10	8	8	6	7	5	6	8	8
	TNOS	12	7	39	46	49	107	20	101	31	16	17	29	71

sources were very limited, natural enemies were generally less abundant than insect pests, especially in the most susceptible period for cashews from pre-flowering flush (April) to fruiting (October) (Table 4). The ratio of natural enemies to insect pests each month was much higher at Howard Springs than at Wildman River (Table 4). This difference may reflect the different periods of time taken for various natural enemies to migrate into the study area once pesticides were withheld. In the samples of October 1994 after 15 months without pesticides, the numbers of samples containing the predator species *O. smaragdina* at Wildman River were close to those at Howard Springs (Table 5), which seems to support the above explanation. However, other natural enemy species such as *Oxyopes* sp., *Coelophora* sp., *Cryptolaemus mountrouzieri* and chalcids were much more abundant at Howard Springs than at Wildman River (Table 3). Some natural enemies such as *Eristalis* sp., *Rhyzobius* sp. and a species of reduviids, only occurred at Howard Springs (Table 3), which supports the hypothesis that there will be a greater abundance and diversity of natural enemies of pest insects in polycultures than in monocultures (Root 1973).

The most important predator species in the cashew plantation is *O. smaragdina*, which can significantly reduce damage caused by the main insect pests *H. pernicialis*, *A. lutescens* and *P. jocosatrix* (Peng *et al.* 1995, in press). At the Howard Springs site, *O. smaragdina* was found in 50–100% of samples obtained at each sampling occasion and they were abundant throughout the year (Table 5). Well established *O. smaragdina* colonies were found on most non-crop trees, and they were able to access the cashew block through many points of contact between non-crop trees and cashews (Peng *et al.* in press) once pesticides were withheld. In contrast, at Wildman River, only a few individuals of this important predator species were caught (Tables 3 and 5). Although there were well established *O. smaragdina* colonies in the surrounding non-crop vegetation area, the distance between native trees and cashews was too far (370 m) for *O. smaragdina* to walk to cashew trees (observations done in this study). This meant that the dispersal of *O. smaragdina* into the Wildman River cashews mainly relied on winged female colonization. During cashew flushing and flowering periods (April–July, Table 4), the populations of the major insect pests, *H. pernicialis*, *A. lutescens* and *P. jocosatrix*, built up quickly due to the lack of efficient natural predators. In particular, an outbreak of *H. pernicialis* occurred at the Wildman River site from July to September (Peng *et al.* 1996), and this resulted in almost no yield (Table 6).

Table 6. Comparison of yield per tree between two sites using group sample t tests, n = 8 trees.

Yield	Wildman River (kg/tree ± SD)	Howard Springs (kg/tree ± SD)	t	p
1993	0.8 ± 1.3	3.2 ± 1.6	4.57	0.008
1994	0.4 ± 1.1	4.7 ± 2.1	4.83	0.001

Note: Trees were eight years old at Wildman River and six years old at Howard Springs, which means the yield at Wildman River should be higher than at Howard Springs.

Co-existence between *O. smaragdina* and homopterans was noted by Das (1959) and Chen (1962). A comparison of abundance of insect pest species between the two sites showed that only homopteran insect pests were more abundant at Howard Springs than at Wildman River (Table 3). A detailed analysis showed that although *O. smaragdina* co-existed with *Aphis gossypii* (Glover) and a species of Pseudococcidae, green ants did not affect the populations of their predators *Coelophora* sp. and *Cryptolaemus montrouzieri* (Mulsant) (Table 3) that were also effective predators of aphids and soft scales of the understorey.

These data demonstrate that non-crop vegetation surrounding cashews and in the understorey provide habitat for arthropods that are predators and parasites of pest species. Furthermore, trees at the site with high ratios of predators to pests had higher yields than the trees at the site with low ratios of predators to pests, which suggests that non-crop vegetation adjacent to and in cashew plantations can increase crop yield.

Acknowledgments

The study was supported by a Postdoctoral Fellowship from the Northern Territory University and a grant from the Rural Industries Research and Development Corporation. We thank Wildman River Plantation, Ian Duncan and Les Brigden for providing us with study sites and necessary facilities. We also thank Graham Brown and Stuart Smith for their permission to use insect collections at the Northern Territory Museum and the Northern Territory Department of Primary Industry and Fisheries.

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