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Implementing ant technology in commercial cashew plantations

and continuation of transplanted green ant colony monitoring

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Foreword

The aim of this project is to continue the monitoring of the transplanted green ant colonies in order to determine how many years cashew growers can benefit from each transplantation and to promote the use of green ant technology in commercial cashew orchards for controlling the main cashew insect pests by producing instructive booklets and posters.

Field monitoring showed that each transplantation of green ant colonies can protect cashew trees for three cropping seasons. Compared with the costs of the insecticide spray, cashew growers can achieve a benefit of at least $1500/ha/year by using green ants to manage the main insect pests. This benefit results from decreased maintenance costs and increased yield.

Age of the ant colony is an important factor influencing the benefit from each transplantation. Green ant colonies at the age about 2 years are considered to be suitable for transplantation.

The green ant technology is described in detail in a booklet "Why and how to use green ants to control the main cashew insect pests - Manual for Australian cashew growers". It covers all aspects of using green ants to control insect pests in cashew plantations. A series of posters was produced to highlight the most important procedures of the ant technology. This technology is friendly to the environment, and therefore cashew products may be marketed as ‘organic’.

Further research regarding development of suitable control methods for yellow tea thrips without devastating green ant populations is suggested.

This project was funded from RIRDC Core Funds which are provided by the Australian Government.

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Simon Hearn
Managing Director
Rural Industries Research and Development Corporation

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Contents

Executive Summary

The aims of this project were completed successfully, and they included the continued monitoring of transplanted green ant colonies at Howard Springs, the production of instructive materials for cashew farmers, and the implementation of the green ant technology in a cashew plantations at LaBelle Downs Station.

Field monitoring showed that the transplanted ant colonies, on average, persisted in the cashew orchards for three cashew cropping seasons. Compared with the costs associated with the insecticide spray area, using green ant colonies to manage the main insect pests allows cashew growers to achieve a savings of $235/ha/year in maintenance costs. Apart from better quality of cashew nuts, trees protected by transplanted ant colonies also produced yields of 861 kg/ha/year more cashew nuts than trees protected by insecticides. The combined benefits of the green ant technology account to at least $1500/ha/year compared to the use of insecticides.

Colony age is an important factor responsible for the period of persistence of the colony in cashew orchards. Our results indicate that colonies between the ages of 1.5 and 2 years are suitable to transplant, and the age is easily determined in the field.

A booklet "Why and how to use green ants to control the main cashew insect pests - Manual for Australian cashew growers" has been written to facilitate the implementation of green ant technology. It covers all aspects of appropriately using green ants to control insect pests in cashew plantations. A series of posters has been made based on the contents of the booklet to highlight the most important procedures of the ant technology. Two field workshops and one training course were held at LaBelle Downs Station and Northern Territory University to transfer the ant technology to cashew growers.

1. Introduction

The tea mosquito bug, the mango tip borer, the fruit spotting bug, the leafroller and the green bug are identified as serious insect pests in cashew plantations of northern Australia (Houston & Malipatil, 1991; Stonedahl, Malipatil & Houston, 1995; Peng, Christian & Gibb 1998a). These insect pests can be successfully controlled by green ants (Peng *et al*., 1995, 1996, 1997a,b, 1998a,b). However, fierce boundary fights between green ant colonies are the major factor limiting the ant populations and their efficiency as biological control agents (Peng *et al*., 1996, 1997a). In our last RIRDC project "Utilisation of the green ant to control cashew insect pests", methods to limit the boundary fights and to stabilise ant populations at the high level have been developed (green ant technology) (Peng *et al*., 1998a, 1999a, b). This ant technology consists of (1) the management of the ants at the colony level, which includes identification and separation of ant colonies, colony transplantation and maintenance, and (2) the mixed-cropping system with suitable host plants for the ants. When we tried to transfer this technology to farm staff, we came to appreciate the need for well-organised and effective instructional materials. We believe that if the technology can be clearly explained in a series of educational posters and booklets, it will be easy for cashew growers to adopt.

In cashew orchards, there are always some trees that are not occupied by green ants. To achieve the maximum protection for cashew orchards from insect pest damage, it is essential to transplant green ant colonies from native vegetation to these trees. A field experiment involving the transplantation of ant colonies with and without queen ants began in April 1997 at Howard Springs Farm as part of our last RIRDC project. Preliminary results indicated that the cost of chemical insecticides was $583/ha, while the cost for introducing and managing ant colonies was $700/ha in 1997. According to our monitoring data, populations of the transplanted colonies with queen ants were large and stable by the end of 1998 (the end of our last project) (Peng, 1999b) with a little field management. The chemical control area had 8 insecticide sprays in 1998 (total costs for insecticides were $446/ha), but the area with introduced ant colonies had very little expenditure and produced better quality nuts and yield than the chemical control area (Peng, 1999a). This indicates that by 1998, the ant area had already achieved a savings of $329/ha from the transplantation of ant colonies in 1997 compared with the cost of the chemical control area. Also, the transplanted colonies were still strong by the end of 1998. In order to determine how many years these transplanted colonies can persist, which will allow cashew growers to assess the benefit they can get from each transplantation, the monitoring of these colonies has continued since December 1998 as part of our current project.

2. Objectives

(1) To continue the monitoring of the population changes in transplanted green ant colonies in order to determine how many years cashew growers can benefit from each transplantation of the ant.

(2) To introduce and promote the use of green ant technology in commercial cashew orchards for the purpose of controlling the main cashew insect pests (the tea mosquito bug, the fruit spotting bug, the mango tip borer, the leafroller and the green bug). This will be accomplished by producing instructive posters and booklets. These instructive materials will highlight key procedures in the stabilisation of populations of existing and transplanted colonies of the green ant. They will be used in field workshops and future consultation for growers.

3. Methodology

This research was done at Northern Territory University, Howard Springs Farm and LaBelle Downs Station in the tropical area of Northern Territory. It was concentrated on two aspects: (1) the monitoring of the transplanted ant colonies at Howard Springs Farm, and (2) implementation of the green ant technology by making posters, writing booklets and running field workshops.

3.1. The monitoring of the transplanted ant colonies

A total of 7 green ant colonies were transplanted into cashew orchards in April 1997; four colonies with queens and three colonies without queens (Peng et al., 1999b). The three colonies without queens all died after the wet season of 1997 (Peng, et al., 1999b), and they were later replaced with new colonies for the purpose of comparison of insect pest damage and yield assessment against the control treatment of insecticides. The four colonies with queens have all survived very well, and their populations were high by the end of 1998 (Peng et al., 1999b). These four colonies have been continuously monitored since then. The population size of each colony was assessed weekly during the dry season (flowering and fruiting period) and fortnightly during the wet season. The same method of monitoring as used in our last RIRDC project was used. That is, in each tree, the number of ant trails on the main branches of the tree was counted. If more than 10 individual ants were counted walking along a main branch, the trail was assigned a value of 1. If less than 10 but more than 1 ant was counted walking along the branch, the trail was assigned a value of 0.5. The insect pest damage on the tree and the numbers of trees occupied by each colony were also recorded.

3.2. Monitoring and assessment of cashew yield for other treatments

In order to assess the differences of the transplanted colonies, four other treatments were used in 1999. These were: the area with isolated existing green ant colonies, the area with green ants but without colony isolation, the area with insecticide spray and the area with no green ants and no spray. In 2000, the same treatments were used except the treatment of isolated existing ant colonies. This is because most colonies in this area were 7 years old, and gradually died after the 1999 wet season. Insect pest damage in these treatments has been monitored weekly during the dry season (flowering and fruiting period), and fortnightly in the wet season. A quadrat which is 1/4 m^2 was used for sampling and counting the number of nuts in the shade area of tree canopies. Four quadrats were measured for each tree, and they were evenly positioned in four directions. Each quadrat was one meter away from the tree base.

Each spray in the control section was initiated by a control threshold suggested by Peng *et al*. (1997b). The numbers of chemicals for each spray and the numbers of spray times each year were recorded. The costs for maintaining transplanted ant colonies were also recorded. The difference was determined by comparing the costs and yields between the treatments over a period of four years (1997 - 2000).

3.3. Measurement of age of green ant colonies

In order to make sure ant colony transplantation is successful, it is important to determine the age of the ant colonies. Body size of queen and worker ants was measured in colonies of known age. A total of 33 colonies with different ages were examined, and these colonies were from Wildman River, Howard Springs and Darwin area.

3.4. Meteorological data

The meteorological data were obtained from the weather station located near the cashew orchard at Howard Springs. The readings from the station were down-loaded on a regular bases.

3.5. Data analysis

The data in percentage and pest numbers were analysed by nonparametric statistics using the SYSTAT statistics package (Wilkinson, 1990). One way ANOVA was used to compare the differences in insect pest damage levels and in yield assessment between the treatments. The group t test method was used to compare the body size of major worker ants and queen ants between different colony ages.

3.6. Implementation of green ant technology

The green ant technology was implemented by writing a booklet, making a series of posters and holding field workshops. A booklet was written in simple language, which concentrated on the important aspects of the green ant technology. A series of posters was made based on the contents of the booklet to highlight the most important procedures of the ant technology. The posters consist of photographs, figures and tables, together with a simple written description. The purpose of these posters is to provide a quick reference and to reinforce the important aspects of the technology. Two field workshops and one training course were held at LaBelle Downs Station and Northern Territory University.

4. Results and discussions

4.1. The monitoring of the transplanted green ant colonies

Of the four colonies with queen ants which were transplanted to Howard Springs cashew orchard in April 1997, colonies 2 and 3 were still surviving at the end of October 2000 (Fig. 1), but colonies 1 and 4 died in July 1999 and in March 2000 respectively (Fig. 2). Colonies 2 and 3 had successfully protected 15 cashew trees from the main insect pests for four cropping seasons (1997 - 2000; Fig. 1). Colony 1 protected 9 trees for two cropping seasons (1997 and 1998; Fig. 2), and colony 4 protected 11 trees for three seasons (1997 - 1999; Fig.2). By the end of October 2000, colony 2 was weak, but colony 3 was still strong and it may survive for another year. These transplanted ant colonies, on average, persisted in the cashew orchards for three cashew cropping seasons.

From examination of population fluctuations over a long period, heavy showers (> 60 mm/event) during the wet season are a major factor responsible for the decline of the ant populations. This effect was temporary when queen ants survived heavy showers (Fig. 1), but was destructive when queen ants were destroyed (Fig. 2).

Colony 1 died in July 1999 (Fig. 2), which was below the average surviving time of the transplanted colonies. The death of the colony was probably due to the age of the colony. In the transplantation process, the records showed that the body size of the queen in colony 1 was bigger than the queens in other three colonies, although it is not known whether the queen size is related to the age. Our study suggests that a green ant colony can live about 7 years (Peng *et al*., 1999b). When these four colonies were transplanted, it was difficult to determine the age of the colonies. So, it could be that colony 1 was older than the other three colonies at the time of the colony transplantation. To determine this, the body size of queens from a number of colonies of known age were measured in August 1999 and 2000. The results show that although the length of head and thorax of queen ants varies little with the age of green ant colonies (9.29 mm ± 0.24), the size of abdomen of queens increases with the age of the ant colonies (Fig. 3). Therefore, the larger queen of colony 1 suggests that this colony was older than the other three colonies, hence it died earlier. This suggests that colony age is an important factor in the process of colony transplantation; the younger the transplanted colonies, the longer they persist in cashew orchards.

4.2. Determination of age of green ant colonies

Although abdomen size of queen ants is positively related to the colony age (Fig. 3), to determine colony age of the ants in the field, this factor is difficult to determine. This is because queen ants are very well protected by many major workers when the queen ant nest is opened, and the queens are easily damaged in the process of removing the workers. Therefore, the body size of the major workers from a number of colonies of known age were measured. The relationship between the body size of major workers and the colony age is shown in Fig. 4. Three points of interest emerge:

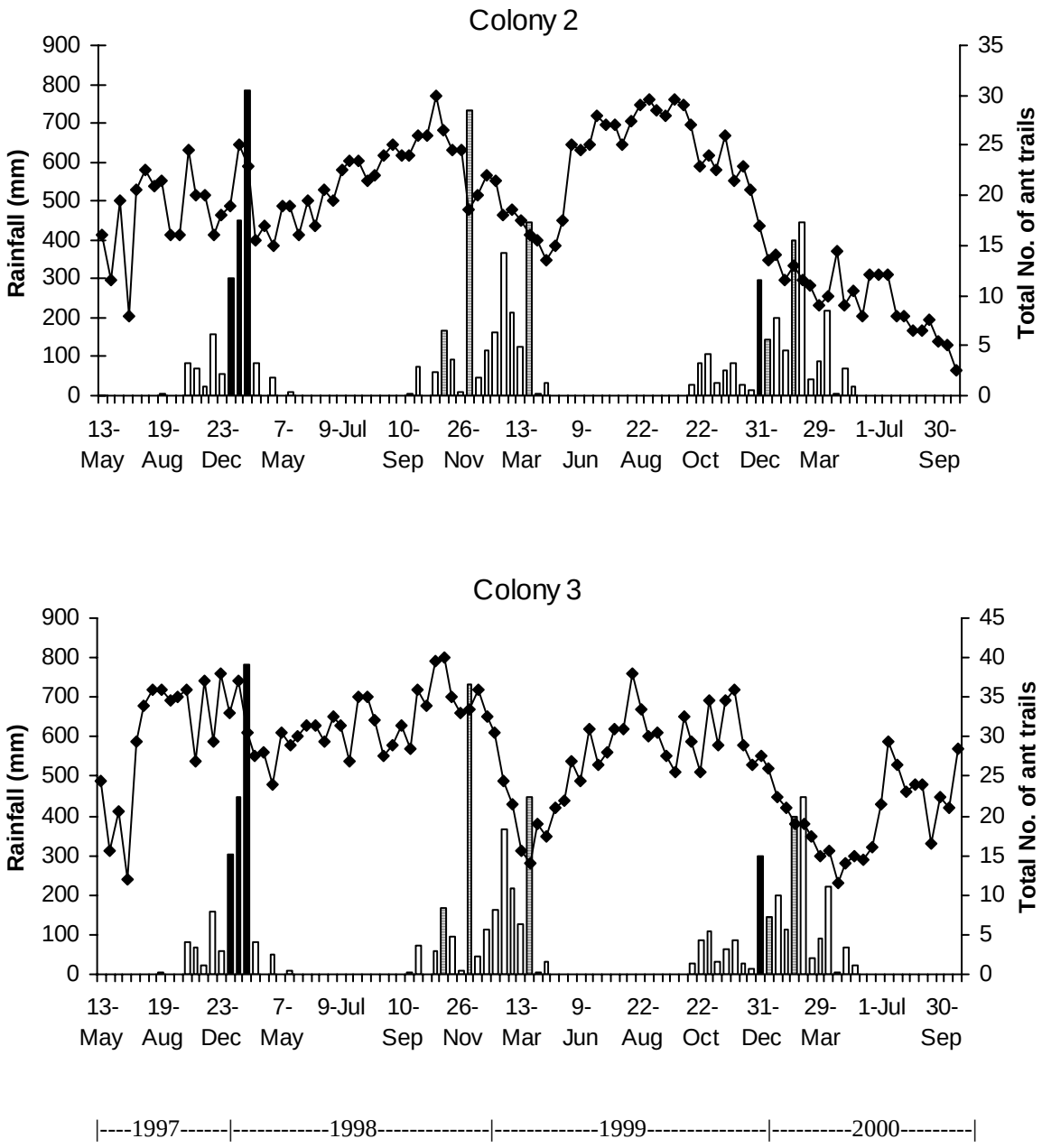

Fig.1. Population fluctuation (curved line with solid diamond) of transplanted colonies 2 and 3 in relation to rainfall (vertical bars).

Rain bars: ▭ with no heavy rainfall over 60 mm/event;
▮ With over two heavy rainfall evens over 60 mm/event;
▯ With one heavy rainfall event over 60 mm/event.

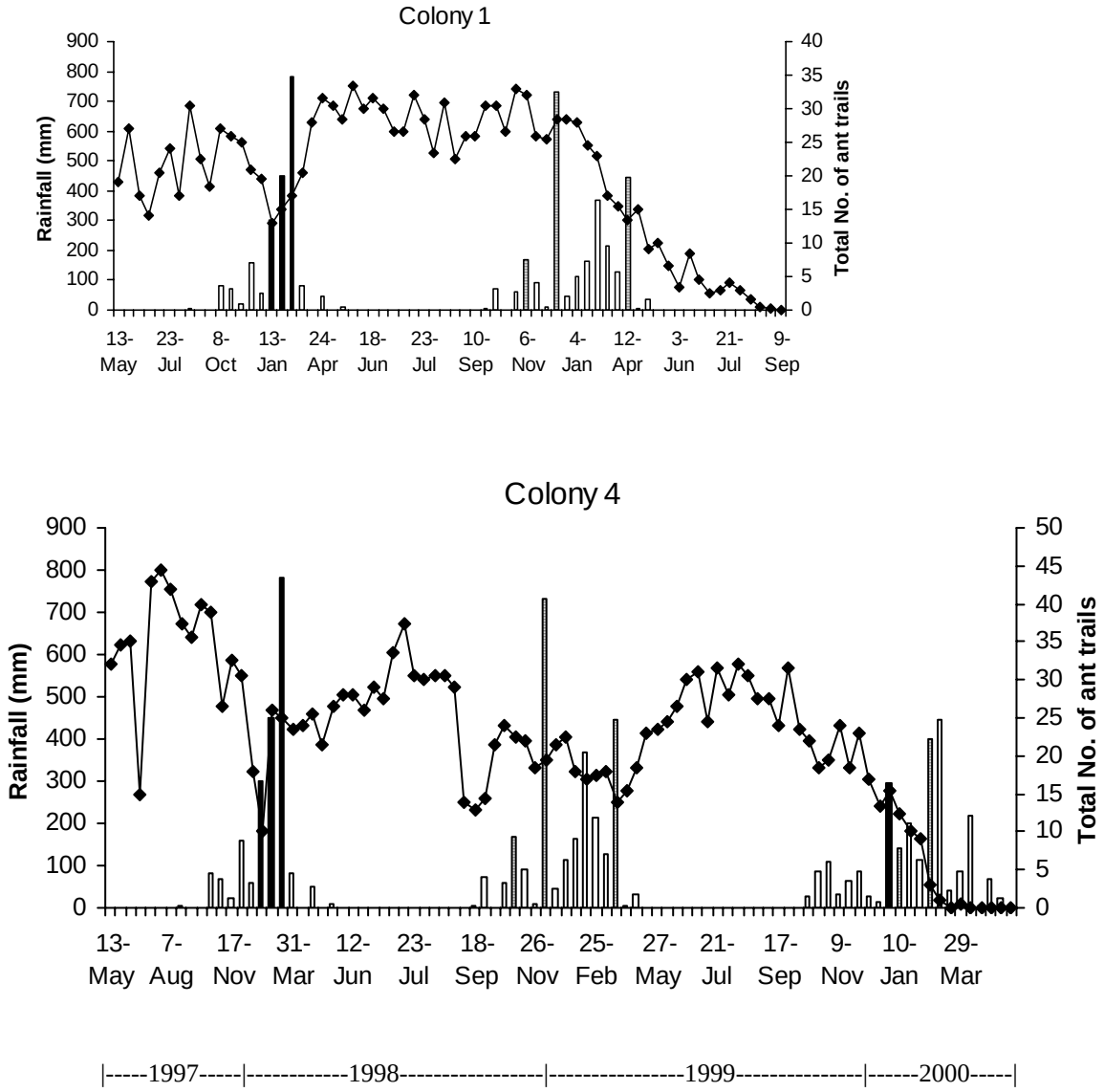

Fig. 2. Population fluctuation (curved line with solid diamond) of transplanted colonies 1 and 4 in relation to rainfall (vertical bars).

Rain bars: ▭ with no heavy rainfall events over 60 mm/event;
▮ With over two heavy rainfall over 60 mm/event;
▥ With one heavy rainfall event over 60 mm/event.

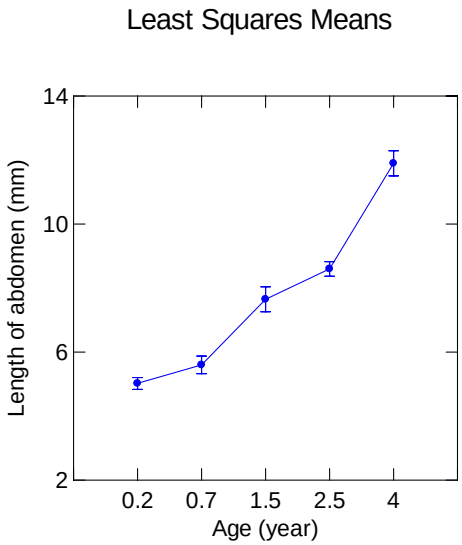

Fig. 3. The relationship between the body length of queen ants and colony age.

(1) When colonies are less than 1.5 years, worker ants are monomorphic, and they are 5.9 ± 0.3 mm long (Fig. 4) and slim. The colony has less than 15 nests, mostly occupying only one tree (occasionally two trees).
(2) When colonies are between 1.5 and 2 years, apart from monomorphic small workers, big body-sized worker ants appear, and they are 7.4 ± 0.5 mm long. The colony has 30 to 60 nests, spreading over two to three trees.
(3) When colonies are over two years old, worker ants are dimorphic; major worker being 7.6 ± 0.4 mm, and minor workers being 4.9 ± 0.9 mm. The colony has over 60 nests, occupying more than four big trees (sometimes many trees).

From this measurement, it is easy to determine the age of green ant colonies which are less than two years old, but it is difficult to distinguish the colony age when they are more than three years old, unless queen ants are measured. In controlling cashew insect pests by transplanting colonies of the ants, two points must be considered: (1) colonies should be as young as possible, and (2) colonies should have large numbers of nests. Based on this, colonies at the age between 1.5 and 2 years are suitable, and they are also easily determined in the field.

4.3. Insect pest damage and yield assessment between treatments

Insect pest monitoring showed that the tea mosquito bug (*Helopeltis pernicialis*) and the leafroller (*Anigraea ochrobasis*) were the major insect pests at the Howard Springs cashew orchard. The damage levels for the three treatments in 1999 and 2000 (the results in 1997 and 1998 were summarised in Peng et al., (1999b)) revealed that in the area of transplanted ant colonies, the damage caused by these two pests was significantly lower than the spray area (Table 1). Heavy damage occurred in the treatment of no green ants and no insecticide spray (Table 1). This difference in damage levels is directly reflected in the yield assessment of cashew nuts. The transplanted colony area produced higher yield than the spray area, and the area without both green ants and insecticides produced the

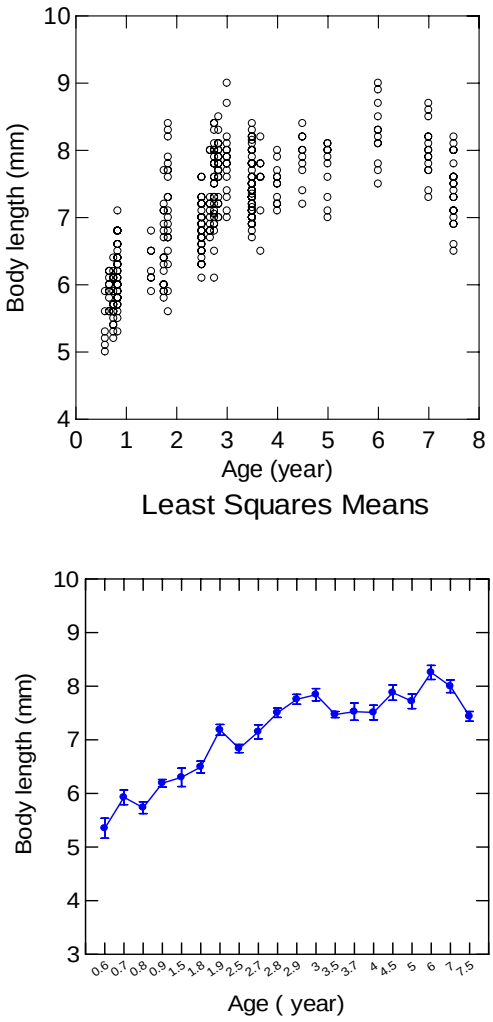

Fig. 4. The relationship between the body length of worker ants and colony age.

lowest yield (Table 2). These results are consistent with the results obtained in 1997 and 1998 (Peng et al., 1999b).

It is noted from Table 2 that yield produced in the area of isolated ant colonies in 1999 was much lower than that from the area of transplanted colonies. This is because in the isolated ant colony area, the ant colonies were 5 to 6 years old according to our records, and had begun to senesce. Ant populations in this area were heavily reduced by a heavy rainfall event of 78 mm on 12 April 1999. Two colonies gradually disappeared by the end of July (Table 2). The remaining 6 colonies survived, but the populations were not as big as they were in 1998. Therefore, some of the trees in this area, which had either no green ants or low numbers of the ants during the period of cashew flowering and fruiting, were damaged by the tea mosquito bug. In contrast, populations of green ants in the transplanted area were high and stable (Figs 1 and 2), and trees in this area were hardly damaged by the main insect pests, resulting higher yield than the area of isolated colonies (Table 2).

Table 1. Mean percentage damage by the main insect pests in the transplanted colony area (TA), the spray area (SA) and the area without both green ants and insecticides (NG) at Howard Springs.

Year	Insect pest	Treatment	Mean ± SD (%)	Incidence
1999	Tea mosquito bug	TA	0.4 ± 0.9 a	June - September
		SA	2.9 ± 2.4 b	
		NG	19.1 ± 14.1 c	
	Leafroller	TA	2.2 ± 2.8 a	May - June
		SA	4.6 ± 2.1 b	
		NG	10.5 ± 4.0 c	
2000	Tea mosquito bug	TA	0.6 ± 0.9 a	July - September
		SA	4.1 ± 2.0 b	
		NG	27.8 ± 14.0 c	
	Leafroller	TA	2.5 ± 3.8 a	May - June
		SA	9.8 ± 1.0 b	
		NG	14.4 ± 8.5 c	

Means followed by the same letter are not significantly different at the 5% level.

Table 2. Yield assessment of cashew nuts between treatments at Howard Springs.

Year	Treatment	No. of Trees	No. of ant colonies Mar.	Oct.	No. of nuts /quadrat	Yield (kg.ha)
1999	Transplanted colony	52	7	7	16.8 ± 6.6 a	2679
	Isolated colony	135	8	6	12.1 ± 5.5 b	1936
	Spray area	40	0	0	12.3 ± 6.4 b	1971
	Not isolated colony	29	3	2	7.4 ± 4.9 c	1189
	No spray & no ants	21	0	0	4.9 ± 4.0 d	787
2000	Transplanted colony	43	7	7	17.9 ± 6.8 a	2871
	Spray area	10	0	0	14.5 ± 6.0 b	2325
	Not isolated colony	46	3	2	10.7 ± 4.9 b	1716
	No spray & no ants	9	0	0	8.3 ± 3.9 c	1331

Means followed by the same letter are not significantly different at the 5% level.

4.4. Implementation of green ant technology

Booklet

A booklet "Why and how to use green ants to control the main cashew insect pests - Manual for Australian cashew growers" has been completed. It is in Appendix 1. We have received a good response from Mr Ian Duncan after the draft was sent off for comments. The booklet has been written in the format of questions and answers. There are 13 questions, which cover all aspects of appropriate use of green ants to control insect pests in cashew plantations. These include the major cashew insect pests that can be controlled by the ants, the efficiency of the green ant on the insect pests, the major problems associated with the use of green ant colonies, the key factors to stabilise ant populations in cashew orchards, the method to plan a new cashew orchard with the use of green ants and the construction of a green ant nursery.

Posters

A series of posters was made based on the contents of the booklet to highlight the most important procedures of the ant technology. The posters include photographs, figures and tables, together with a simple written description. The posters are in Appendix 2.

Field workshops

Two field workshops and one training course were held at LaBelle Downs Station and the Northern Territory University. The first workshop concentrated on the identification of major insect pests and their damage, monitoring time and procedure, the effectiveness of controlling the major insect pests (the tea mosquito bug) by green ants, and field management in relation to the use of green ants. In the second field workshop, we demonstrated the technology of managing green ant colonies. Two complete green ant colonies were identified, picked up and transplanted into cashew orchards. Trees within each colony were linked by polystrings to promote ant communication. We also set up procedures for the colony maintenance. In the training course, participants were trained to identify the major cashew insect pests and were given an overview of green ant biology, including colony structure, colony activity patterns, ant behaviour within and between colonies, and colony development.

Field workshops should be held at Cashews Northern Territory at Wildman River and Cashews Australia at Dimbulah in the northern Queensland as proposed in the research proposal. However, this has not happened because Cashews Northern Territory at Wildman River has been on hold during 1999 and 2000, and there were no farm staff available to be trained with the technology. Dimbulah is far from Darwin, and financial assistance was not available. However, this ant technology will be made available for them to use, and we will be available for consultation and trouble-shooting of the technology in the future.

5. Implications

5.1. Economic benefits

At Howard Springs, the costs associated with the chemical control area and with the transplanted ant colony area are shown in Table 3. For the four transplanted green ant colonies, colonies 2 and 4 protected cashew trees for four cropping seasons (1997 - 2000; Fig. 1), and each colony achieved a savings of $265/ha/year. Colony 1 protected trees for two seasons (1997 and 1998; Fig. 2), and a savings of $155/ha/year was achieved. Colony 4 protected trees for three cropping seasons (1997 - 1999), and it achieved a savings of $254/ha/year. In this experiment, colonies persisted in cashew orchards for three cropping seasons on average. Therefore, compared to the costs in chemical control area, the area protected by transplanted ant colonies achieved a savings of $235/ha/year.

Table 3. Costs for maintaining insecticide spray area and transplanted ant colony area.

Year	Area with insecticides ($/ha)	Area with transplanted ant colonies ($/ha)
1997	583	700
1998	446	20
1999	502	50
2000	335	35
Total	1866	805

With respect to the quality of cashew nuts, when trees are protected by green ant colonies, no insecticides are needed because the main insect pests are controlled by the ants. Therefore, cashew nuts produced by these trees have no insecticide residue. In addition, in the nut development stage, young nuts continuously secrete extrafloral nectar (Rickson & Rickson, 1998), and this nectar is continuously taken away by green ants, and thus, trees with green ants produce clean and shining nuts. However, with insecticide spray, the nectar is continuously deposited on the inside curve of nuts, resulting in a black residue on the nuts due to fungus invasion. The nuts produced by these trees have sooty mould and look dull.

With respect to cashew nut yield, a comparison of the yield between the chemical control area and the transplanted ant colony area is shown in Table 4. Trees with transplanted ant colonies produced an average of 861 kg nuts more than trees protected by insecticides. This would be $1,292 if one kilogram raw nuts is worth $1.50 (a low price, according to Mr Ian Duncan). After taking into account the savings compared to the use of insecticides, trees protected by green ant colonies produce a benefit of $1,527/ha/year ($1292 +$235).

In summary, the method of using the green ant can bring cashew growers an extra benefit of at least $1500/ha/year.

Table 4. Assessment of average yield in the chemical control area and the transplanted ant colony area.

Year	Treatment	No. of trees	No. of nuts/quadrat	Yield (kg/ha)
1998	Transplanted colony	52	14.6 ± 7.4 a	2342
	Spray area	40	6.3 ± 5.9 b	1012
1999	Transplanted colony	52	16.8 ± 6.6 a	2679
	Spray area	40	12.3 ± 6.4 b	1971
2000	Transplanted colony	43	17.9 ± 6.8 a	2871
	Spray	10	14.5 ± 6.0 b	2325

Means followed by the same letter are not significantly different at the 5% level.

5.2. Benefit to environment

When green ants are used to control the main insect pests in cashew orchards, chemical spray with insecticides can be greatly reduced or no longer needed. This will significantly reduce air, soil and water pollution to the environment, and there is no chemical residue in cashew nuts. Therefore, cashew nuts produced by this technology can be regarded as ‘organic’. This marketing advantage may further inflate the economic benefits of using green ants as compared to insecticides.

5.3. No impact on other organisms

As cashew nuts are harvested from the ground, farm staff do not need to worry about the aggressive behaviour of green ants. Also, green ants have no impact on arthropod diversity and other general predators and parasitoids in cashew orchards (Peng et al., 1999b).

6. Recommendations

6.1. Development of suitable control methods for yellow tea thrips without devastating green ant populations

Use of insecticides at Wildman River has been stopped since 1996, and green ants have occupied most trees in every block and the main insect pests are under control. However, in the 1997 crop season, some patches of cashew trees in the plantation were damaged by yellow tea thrips, *Scirtothrips dorsalis* Hood, which was only seen in small numbers but was not recorded as a pest before 1996. In 1998, this pest species spread so quickly that most trees in Bore Block were affected.

According to preliminary observations (Peng et al., 1999b), these thrips mainly feed on young nuts and apples. When nuts starts to set (middle of June), the thrips appeared and fed on the area between the nut and the small peduncle. As the nut and the apple grow bigger, the thrips move to the surface of the nut and apple. Apples have at least one or more longitudinal cracks when they are moderately or seriously damaged, which resulted in poor nut quality (Peng et al., 1999b).

Although green ants have some control efficiency on yellow tea thrips (Peng et al., 1999b), cashew nuts were still moderately or seriously damaged by the thrips in the area with abundant green ants. This may be not acceptable to cashew growers. Therefore, it is necessary to try a range of soft insecticides which can be used to control yellow tea thrips without devastating green ant populations. Some natural or low toxic insecticides, such as petroleum spray oils (Ian Baker, pers. comm.), neem oil and Buprofezin (insect hormone pesticide), are effective to control thrips, but their impact on green ants must be assessed.

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Appendix 1 Booklet: Why and how to use green ants to control the main cashew insect pests - Manual for Australian cashew growers

Why and how to use green ants to control the main cashew insect pests - Manual for Australian cashew growers

Manual for Australian cashew growers

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Introduction

Cashews have substantial potential for development in northern Australia. Several small scale cashew plantations have been established since 1985. Unfortunately, they encounter severe insect pest problems, and the main insect pests in mature orchards are sap sucking bugs, leaf chewing caterpillars and leaf beetles (Houston and Malipatil, 1991). A study undertaken by Peng, Christian and Gibb (1998) revealed that the green ant plays a very important role in regulating the populations of the above three groups of insect pests in cashew plantations. However, fierce boundary fights between green ant colonies are the major factor limiting the ant populations and their control efficiency. These fights can be prevented, and the methods for using green ants to manage the main cashew insect pests (ant technology) have been developed and tested (Peng *et al*., 1999a). This ant technology achieves higher yield with lower costs than the use of chemical insecticides. The technology is also friendly to the environment, and it can bring a significant benefit to cashew growers, including the production of 'organic' products.

The aim of this booklet is to summarise the effective control of the main insect pests by green ants and to describe the implementation of the ant technology in cashew orchards step by step. This ant technology consists of three components: (1) management of the ants at the colony level, (2) a mixed-cropping system in cashew orchards and (3) construction of the ant nursery. This technology is completely different from traditional Asian methods of using the ants, in which the ants were inefficiently and expensively managed at the nest level. The booklet also answers questions often asked by cashew growers with respect to the use of the ants.

This booklet is based on the results of a series of research projects undertaken between 1993 and 2000 at the Wildman River Cashew Plantation and at Howard Springs in the wet-dry tropical area of the Northern Territory. The ant technology has been developed in the context of the biological and environmental conditions in the Top End. Because the insect pest complex and cashew growing conditions of cashew orchards in the northern Queensland are similar to the Northern Territory, this booklet can be used for all existing and potential cashew growers in northern Australia. This booklet can also be used as an important reference for other tropical growers who are engaged in the production of mango, macadamia, avocado, citrus, coconut, cocoa, cassava, lychee and pawpaw because of overlap of the major insect pests between these crops and cashews.

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1. What are the main insect pests in cashew orchards, and what is the control efficiency by green ants?

Based on cashew insect pest research over the last ten years, more than 20 species of insects damage cashew twigs, leaves, flowers, fruits and nuts in northern Australia (Houston and Malipatil, 1991; Stonedahl, Malipatil and Houston, 1995; Peng, Christian and Gibb, 1995, 1999a). Among these, the main insect pests are:

- the tea mosquito bug, *Helopeltis pernicialis* (Hemiptera: Miridae);
- the fruit spotting bug, *Amblypelta lutescens* (Hemiptera: Coreidae);
- the mango tip borer, *Penicillaria jocosatrix* (Lepidoptera: Noctuidae);
- the leafroller, *Anigraea ochrobasis* (Lepidoptera: Noctuidae); and
- the green vegetable bug, *Nezara vividula* (Hemiptera: Pentatomidae).

These insect pests can be successfully controlled by green ants, *Oecophylla smaragdina* (Hymenoptera: Formicidae) (Peng et al., 1995, 1997a, b, c, 1998a, 1999a,b). For each species, the morphology, damage, incidence and control efficiency by green ants are described below.

1.1 The tea mosquito bug

1.1.1 Morphology

The nymphs and adults of the tea mosquito bug damage cashew trees. Figures 1a and b show what nymphs and adults look like.

1.1.2 Damage and economic importance

The tea mosquito bug damages cashew trees by sucking juice from tender part of the trees. Both adults and nymphs attack growing tips, foliar and floral flush, apples and nuts. Damaged young leaves have small reddish black patches over the leaf's surface. Midrib and veins are their preferred feeding sites with the result of disfiguration of the leaf (Fig. 1b). When growing tips, apples and nuts are damaged, sunken and oval-shaped black pits appear. Damage to flushing leaf terminals and inflorescences are signified by the presence of superficial blackened patches (Fig. 1a, b).

Often, the damage on foliar and floral shoots caused by tea mosquito bugs results in die-back of the shoots, and in severe cases, entire foliar and floral flushes are destroyed. Crop loss due to this pest at Wildman River between 1994 and 1997 was between 48 % and 95% (Peng et al., 1997a,b; 1999a,b).

1.1.3 Incidence

This pest lives on cashews throughout the year. The numbers are closely related to the foliar and floral flushing periods of cashews. According to the work by Peng, Christian and Gibb (1997a,b; 1998a), the peak outbreak of the pest is in the flowering and fruiting period of the crop, which is usually between June and August in the dry season (Table 1).

Table 1. Seasonal abundance of the main insect pests in cashew plantations in the Northern Territory.

*, **, *** or **** refers to the abundance level of each species from the least to the most abundant.

Month	Oct - Dec	Feb - Mar	Apr - May	Jun - Aug
Tree phenology	Post-harvest flush	Monsoon flush	Pre-flowering flush	Flowering & fruiting
Tea mosquito bug	**	**	***	****
Fruit spotting bug	***	***	**	***
Mango tip borer	***	****	**	*
Leafroller	*	***	****	**
Green vegetable bug	*	*	**	****

1.1.4 Control efficiency by green ants

Nymphs were captured by green ants (Fig. 1c), and adults were often chased away from feeding sites on flushing shoots by green ants. According to field surveys done in 1993 and 1994, only 3 - 7% of trees fully colonised by green ants were damaged by tea mosquito bugs. Of the trees partly colonised by the ant, 18 - 27% were damaged. However, for trees without green ants, 50 - 52% of them were damaged (Table 2).

Table 2. The effect of green ant colonisation on tea mosquito infestation. Data are from Peng et al. (1995).

Year	Category	Levels of green ant colonisation[1]		
		Full	Part	None
1993	Total number of trees inspected	168	68	175
	Trees damaged by the pest	5	12	88
	% damage	3	18	50
1994	Total number of trees inspected	147	105	105
	Trees damaged by the pest	10	28	55
	% damage	7	27	52

[1] "Full" refers to trees with green ants with two or more nests; "Part" refers to trees with small numbers of ants with less than two nests; "None" refers to trees without green ants.

Between 1994 and 1995, two adjacent eight-year-old cashew trees of the same variety and of the similar size were closely observed. Green ant populations were larger and more stable on tree 1 than on tree 2; the number of ant nests was never less than 10 on tree 1 over the two years, but the number of ant nests often dropped to zero on tree 2 (Peng et al., 1997a). During flowering and fruiting periods in which there were no green ants on

tree 2, the damage by tea mosquito bugs was 45% of all flushing shoots in 1994 and over 80% of all flushing shoots in 1995. At the same periods, however, tea mosquito bug damage on tree 1 was less than 1% of all flushing shoots in 1994 and only 8% of all flushing shoots in 1995 (Peng et al., 1997a). This resulted in great difference in yield; the yield from tree 1 was two and seven times the yield from tree 2 in 1994 and 1995 respectively (Table 3).

Large field surveys in 1993 and 1994 showed that trees with green ant nests were significantly less damaged by tea mosquito bugs than those without the ant nests (Table 4).

Fig. 1 - colour photos of green ants and cashew insect pests

From the data presented above, it is concluded that green ants are efficient biological control agents of the tea mosquito bug.

Table 3. Comparison of the yield between two trees which were the same variety and grew next to each other. Tree 1 was continuously occupied by green ants, but tree 2 was only intermittently occupied by the ants. Data are from Peng et al. (1997a).

Year	Tree 1	Tree 2
1994	8.6 kg	4.5 kg
1995	7.2 kg	1.0 kg

Table 4. Cashew flushing shoots damaged by the tea mosquito bug with respect to the number of green ant nests per cashew tree. Data are from Peng et al. (1997c).

Site	No. of ant nests per tree	Date: Nov. 1993		Apr. 1994		Sep. 1994	
		Average damage ± SD	No. of trees	Average damage ± SD	No. of trees	Average damage ± SD	No. of trees
Wildman River	0	11.0 ± 1.2	91	3.0 ± 1.4	5	21.5 ± 2.9	48
	1 - 2	1.1 ± 0.4	113	0.0 ± 0.0	144	4.1 ± 0.7	169
	3 - 4	0.0 ± 0.0	31	0.0 ± 0.0	21	3.9 ± 0.9	50
	> 4	0.0 ± 0.0	19	0.0 ± 0.0	9	1.4 ± 0.5	29
Howard Springs	0	33.4 ± 4.7	37	—		—	
	1 - 2	0.0 ± 0.0	106				
	3 - 4	0.0 ± 0.0	43				
	> 4	0.0 ± 0.0	47				

1.2 The fruit spotting bug

1.2.1 Morphology

Like tea mosquito bugs, the nymphs and adults of the fruit spotting bug damage cashew trees. The appearance of the nymph and adult is shown in Figures 1d and f.

1.2.2 Damage and economic importance

The fruit spotting bug damages cashew trees by sucking juice from tender shoots and young nuts. Both adults and nymphs feed on flushing leaf terminals, flowering panicles, apples and nuts. Similar to tea mosquito bugs, this pest also causes the development of necrotic lesions. However, the damage symptoms caused by fruit spotting bugs are characteristically different from those of the tea mosquito bug. Following feeding, the damaged area develops an elongated, blackened and sunken lesion (Fig. 1e), and later becomes a depressed hardening lesion. Necrotic lesions also occur on damaged apples and young nuts, and these lesions are shallower and more diffuse than the damage caused by tea mosquito bugs. Damaged flushing shoots and flower panicles will die, damaged growing tips will stop growing and damaged young nuts will have early abortion. No information is available about the loss of yield due to this insect pest, but field observations suggest that the fruit spotting bug is an important pest in cashew orchards (Peter Shearer, person. comm.; Peng et al., unpubl. data).

1.2.3 Incidence

This pest lives in cashew orchards throughout the year. They are very active and tend to hide when they are seen. Normally, they do not stay on the shoots that have already been damaged by them. The numbers of this insect pest seen in cashew orchards are not high, but shoots damaged by them are easily seen in the field. The incidence of this pest is closely associated with cashew flush periods (Table 1, Peng, unpublished data).

1.2.4 Control efficiency by green ants

Nymphs are caught by green ants (Fig. 1f). When fruit spotting bugs were abundant in cashew orchards at Wildman River, a field survey was done in 1993 and vacuum samples were taken in 1996. The results are listed in Table 5. Trees with abundant green ants were much less damaged or had fewer numbers of the pest than trees without green ants.

Field surveys in 1993 and 1994 showed that the trees without green ant nests were much more seriously damaged by fruit spotting bugs (9.2 - 24%) than those with ant nests (0 - 3.9%; Table 6).

These results suggest that green ants can significantly control fruit spotting bugs in cashew plantations.

Table 5. The effect of green ants on the fruit spotting bug. Data are from Peng et al. (1995; 1999a).

Trees with	November 1993		July - August 1996	
	Damaged shoots ± SD (%)	No. of trees inspected	Mean No. of individuals	No. of vacuum samples
Green ants	3.9 ± 0.6	234	0.0 ± 0.0	60
No green ants	23.4 ± 1.5	94	6.4 ± 6.6	60

Table 6. Cashew flushing shoots damaged by the fruit spotting bug with respect to the number of green ant nests per cashew tree at Wildman River Plantation. Data are from Peng et al. (1997c).

No. of ant nests per tree	Nov. 1993		Apr. 1994		Sep. 1994	
	Average damage ± SD (%)	No. of trees	Average damage ± SD (%)	No. of trees	Average damage ± SD (%)	No. of trees
0	20.4 ± 1.0	186	9.2 ± 1.0	64	24.0 ± 2.8	33
1 - 2	3.9 ± 0.9	113	0.4 ± 0.2	144	1.5 ± 0.5	169
3 - 4	1.0 ± 0.4	31	0.4 ± 0.3	21	1.3 ± 0.5	50
> 4	0.3 ± 0.2	19	0.0 ± 0.0	9	2.4 ± 0.9	29

1.3 The mango tip borer

1.3.1 Morphology

The larvae of the mango tip borer damage cashews. Figure 2 shows the external characteristics of the larvae (Fig. 2a). Larvae have two colour morphs (see Fig. 2a for detail).

1.3.2 Damage and economic importance

The larvae (caterpillar) of the mango tip borer damage cashew trees by chewing young leaves. Larvae feed predominantly at night with activity commencing late afternoon and continuing through to early morning. They prefer the tender leaves of newly emerged leaf flushes. Early instar larvae confine their feeding to the leaf margins, scraping the leaf surface and causing a window effect. Old stage larvae consume large portions of leaf surface, sometimes leaving only the midribs (Fig. 2a). When larvae populations are high on trees, all the tender flushing leaves are removed from the trees (Fig. 2a). Under these conditions, larvae feed on the skin of fruits and the soft shell of young nuts. Although the incidence of nut damage is low, cashew yield is sometimes affected.

1.3.3 Incidence

This pest lives on cashews throughout the year. In general, it is most abundant in cashew orchards during the wet season (October to April; Table 1).

1.3.4 Control efficiency by green ants

During mango tip borer outbreaks, large numbers of larvae are caught by green ants (Fig. 2b). When mango tip borers were in outbreak in November 1993, field surveys were carried out at two sites: Wildman River and Howard Springs. The results showed that for trees with green ants, only 4 -10% of leaf flushing shoots were damaged by the mango tip borer, while for trees without green ants, 28 - 36% of flushing shoots were damaged (Table 7).

Field surveys done in 1993 and 1994 revealed that for each site, trees without green ant nests were more seriously damaged by mango tip borers than those with ant nests (Table 8). This result was consistent between the different survey periods. Field observations in 1997 at Howard Springs also showed that only 3.7% of leaf flushing shoots were damaged on trees fully colonised by green ants, but 15.8% of flushing shoots were attacked on trees without green ants (Peng et al., 1999a).

In conclusion, green ants can significantly reduce the leaf damage by the mango tip borer.

Table 7. The effect of green ants on the mango tip borer, November 1993. Data are from Peng et al. (1995).

Trees with	Average percentage of flushing shoots damaged by the mango tip borer			
	Wildman River		Howard Springs	
	No. of trees surveyed	Damage ± SD	No. of trees surveyed	Damage ± SD
Green ants	234	10.0 ± 0.8	263	3.6 ± 0.5
No green ants	94	28.5 ± 1.9	107	36.0 ± 1.8

Fig. 2 - colour photos of green ants and cashew insect pests

Table 8. Cashew flushing shoots damaged by the mango tip borer with respect to the number of green ant nests per cashew tree. Data are from Peng et al. (1997c).

Site	No. of ant nests per tree	Date: Nov. 1993 Average damage ± SD	Nov. 1993 No. of trees	Apr. 1994 Average damage ± SD	Apr. 1994 No. of trees	Sep. 1994 Average damage ± SD	Sep. 1994 No. of trees
Wildman River	0	25.5 ± 1.1	230	10.3 ± 1.3	59	26.1 ± 2.5	65
	1 – 2	9.6 ± 1.1	113	0.7 ± 0.2	144	7.2 ± 0.9	169
	3 – 4	7.2 ± 2.2	31	0.3 ± 0.2	21	7.4 ± 1.5	50
	> 4	3.5 ± 2.1	19	0.1 ± 0.0	9	9.4 ± 1.6	29
Howard Springs	0	31.0 ± 1.5	159	18.8 ± 1.4	90	6.1 ± 2.7	8
	1 – 2	3.6 ± 0.9	106	4.2 ± 1.0	65	0.5 ± 0.2	76
	3 – 4	1.1 ± 0.4	43	2.9 ± 2.2	12	0.1 ± 0.1	26
	> 4	0.1 ± 0.0	47	2.8 ± 0.4	10	0.0 ± 0.0	47

1.4 The leafroller

1.4.1 Morphology

The larvae (caterpillar) of the leafroller damage cashew trees. The appearance of larvae and the damage symptoms is shown in Fig. 2c and d.

1.4.2 Damage and economic importance

The leafroller larvae chew tender newly emerged leaves by making a scroll of leaves. First instar larvae are found on the underside of tender leaves feeding along the leaf margin, and they do not make a leafscroll. Second instar larvae web the upper opposing margins of the leaf together to form a semi-leafscroll, and they feed within it. As the larvae mature, they web many young leaves together to form a complete leafscroll (Fig. 2c). The larvae feed within this leafscroll, chewing the inner leaves first and progressing to the outer leaves. Normally, the larvae leave outer leaves of the leafscroll intact before they move to another leaf terminal and repeat the process.

Normally, the larvae move onto the next feeding site without damaging the growing tip. The leafroller larvae can defoliate a whole tree when their populations are high, especially when flushing availability is low, the larvae continue to feed on the growing tips and the inflorescence. Whether the yield of cashews is affected by the leafroller is not known, but based on field observations, heavy damage affects the development of tree canopy during the periods of monsoon flush and pre-flowering flush, particularly in young trees. So, control of this pest is necessary in cashew orchards.

1.4.3 Incidence

The leafroller incidence is closely associated with cashew leaf flush periods (Table 1), with highest abundance being between March and June (Table 1).

1.4.4 Control efficiency by green ants

Early instar larvae of the leafrollor are a good food source for green ants (Fig. 2d). A field survey in 1994 shows that the trees with green ant nests were much less damaged by the leafroller than those without green ant nests (Table 9). Field monitoring carried out in 1996 and 1998 demonstrated that trees fully colonised by green ants were almost free from leafroller damage, but trees without green ants had either high numbers of leafroller larvae or a high percentage of shoots damaged by the larvae (Table 9). From these data, it can be said that green ants can substantially reduce the leaf damage caused by the leafroller in cashew orchards.

Table 9. Cashew flushing shoots damaged by the leafroller with respect to the abundance of green ants. Data are from Peng et al. (1997c; 1999a,b).

Field survey			Field monitoring			
1994 (September)			1996 (June-August, Nov.)		1998 (March-June, Sep.)	
No. of green ant nests/tree	Damaged shoots (%)	No. of trees examined	Trees with	Average No. of leafrollers	Trees with	Damaged shoots (%)
0	10.8 ± 3.6	15	Green ants	1.0 ± 0.7	Green ants	0.6 ± 0.5
1 - 2	0.9 ± 0.5	169	No green ants	9.1 ± 3.9	No green ants	9.1 ± 5.0
3 - 4	1.1 ± 0.7	50				
> 4	0.9 ± 0.6	29				

1.5 The green vegetable bug

1.5.1 Morphology

The adults of the green vegetable bug damage cashews. The appearance of the adult and damaged nuts is shown in Fig. 2e.

1.5.2 Damage and economic importance

Adults of the green vegetable bug damage young cashew nuts by sucking juice from them. When young nuts are sucked by the bugs, one day later the light green shining surface of nuts becomes dark green and dull. On the second day, the dark green turns to black and the nuts start to shrink (Fig. 2e). Starting from the third day, the damaged nuts gradually become black and hard, and die. Field observations suggested that any young nuts sucked by green vegetable bugs resulted in early abortion.

About 25% of cashew yield in some blocks of mature orchards at Wildman River in 1996 were lost due to green vegetable bug damage.

1.5.3 Incidence

Adults of the green vegetable bug can be seen in cashew plantations throughout the year. High numbers occur between June and August, when cashew nuts start to set and grow (Table 1).

1.5.4 Control efficiency by green ants

When green vegetable bugs were abundant in the flowering and fruiting period of cashews (June - August, 1996), their populations were monitored in two areas (with and without green ants) by taking regular vacuum samples (Peng et al., 1999a,b). In the area occupied by green ants, both numbers of green vegetable bugs and damaged young nuts were seldom seen. In contrast, in the area without green ants, the bugs and the damaged immature nuts were easily seen, and high numbers of the bug were caught in each vacuum sample (Table 10). Most trees in the area without green ants produced no yield, but trees fully colonised by green ants produced 10 kg/tree (Table 10). This suggests that green ants can successfully protect cashew trees from young nutfall caused by the green vegetable bug.

Table 10. Average number of green vegetable bugs per sample in areas with or without green ants, at Wildman River in 1996. Data are from Peng et al. (1999a).

Orchard	Average no. ± SD	Average yield (kg/tree)*	Sample size
100% trees with green ants	0.0 ± 0.0 a	10.5 ± 2.1 a	35
58% trees with green ants	0.1 ± 0.3 a	5.7 ± 4.1 b	35
No green ants	3.3 ± 3.6 b	0.6 ± 1.2 c	35

* Yield loss in the orchards was due to the damage done jointly by tea mosquito bugs, fruit spotting bugs and green vegetable bugs. Green vegetable bugs were assessed to contribute 25% loss of the yield.

2. Can green ants increase cashew yield, and what are the costs and benefits of using green ants compared with insecticides?

2.1 The effect of green ant colonisation levels on cashew yield

Large-scale surveys, which were done from 1996 to 1998, showed that trees fully occupied by green ants always produced highest yield, and trees with low presence of the ants or trees without the ants produced lowest yield each year (Table 11). This is because trees with abundant green ants were almost free from the damage by the major insect pests (tea mosquito bugs, fruit spotting bugs, mango tip borers and leafrollers), but trees without green ants or with low numbers of green ants were heavily attacked by these insect pests.

Table 11. The effect of the abundance of green ants on cashew yield in blocks A and B. Data are from Peng et al. (1999b).

Block (size)	Colonisat-ion type[1]	1996 (one year no pesticides)		1997 (two years no pesticides)		1998 (three years no pesticides)	
		No. of trees	Mean yield ± SD (kg/tree)[2]	No. of trees	Mean yield ± SD (kg/tree)	No. of trees	Mean yield ± SD (kg/tree)
A	Full	91	2.80 ± 2.84 a	211	7.88 ± 6.22 a	160	6.17 ± 4.31 a
(2.5 ha)	Part	70	0.92 ± 1.30 b	151	5.20 ± 4.25 b	141	4.83 ± 3.08 b
	Present	79	0.36 ± 0.72 c	38	1.60 ± 1.96 c	41	4.19 ± 2.73 b
	None	197	0.14 ± 0.48 c	47	2.25 ± 3.44 c	102	4.18 ± 2.25 b
B	Full	221	7.66 ± 3.92 a	117	7.79 ± 4.46 a	164	5.17 ± 2.57 a
(2.3 ha)	Part	118	4.42 ± 2.72 b	149	5.47 ± 4.13 b	89	3.69 ± 2.15 b
	Present	48	1.82 ± 1.58 c	63	3.36 ± 2.38 c	21	3.64 ± 1.82 b
	None	38	1.62 ± 1.44 c	73	3.39 ± 2.34 c	114	3.08 ± 1.40 b

[1] "Full" refers to more than one green ant trail/tree on the main branches; "Part", with 0.5 - 1 ant trails/tree; "Present", with green ants, but no obvious trails.
[2] Means followed by the same letter are not significantly different at the 5% level.

In the their field surveys and experiments over a period of four years, Peng et al. (1999c) demonstrated that the higher the levels of green ant colonisation in cashew orchards, the higher the yield in the orchards.

2.2 Costs and benefits

According to the field experiments between 1996 and 1999 by Peng et al. (1999b,c) in the Northern Territory, the orchards protected by green ants gave an extra benefit of at least $1100/ha/year compared with the income from chemical control (Table 12).

In addition to this, trees with green ants produce better quality nuts than those protected by insecticides. In the nut developmental stage, young nuts continuously secrete extrafloral nectar (Reckson and Reckson, 1998). This nectar is continuously taken away by green ants, and thus, trees with green ants produce clean and shining nuts. However, with insecticide spray, the nectar is continuously deposited on the inside curve of nuts, resulting in a black residue on the nuts due to fungus invasion. The nuts produced by trees sprayed with insecticides have sooty mould, and look dull.

Table 12. The comparison of cashew yield and expenditure between the use of green ants and insecticides. Data are from Peng et al. (1999b,c).

Cashew Orchards	Trees protected by	Tree age (year)	Yield/ha (kg)	Expenditure ($/ha)	Gross income ($/ha)*	Net income ($/ha)	Profit ($/ha)
Wildman River	Green ants	7	1724	180	3448	3268	1104
	Insecticides	7	1239	332	2478	2164	__
Howard Springs	Green ants	7.5	2071	360	4142	3782	2273
	Insecticides	7.5	1012	515	2024	1509	__

* Gross income is calculated by yield multiplied by $2.00/kg (I. Duncan, pers. comm.).

2.3 Disadvantages of chemical control

If growers have appropriate pest monitoring programs, spraying cashew orchards with chemical pesticides can achieve a good level of insect pest control, but additional disadvantages exist. These are as follows:

- Reduction of pollinators;
  Cashew is an insect pollinated crop, and insecticide spray is detrimental to wasps.
- Pest resistance to chemicals;
  There is a potential problem of pests gaining resistance to chemicals where they are used on a regular basis.
- Chemical residue;
  The market, especially in USA, Europe and Australia, is becoming increasingly conscious of chemical residues in cashew nuts, and regulations to this effect can be expected to increase.
- Environmental pollution.
  A regular use of insecticides will pollute air, water and soil, on which farmers and farm animals have to rely.

It is clear that all these disadvantages can be overcome if green ants are used to manage the main insect pests in cashew orchards.

3. Why do green ants protect cashew trees?

Green ants feed on two forms of food:

- sugar solution and
- insects.

3.1 Sugar solution

The tender leaves, inflorescence, flowers and developing nuts of cashew trees secret large amount of nectar from a large number of extrafloral nectaries (Rickson and Rickson, 1998). This nectar provides green ants with a good food source of sugar solution.

3.2 Insects

Cashew flushing shoots, flowers and developing nuts are always attractive to a range of arthropods, mainly insects including insect pests. These arthropods are a good food source for green ants.

In order to catch their prey and feed on nectar, green ants continuously patrol flushing terminals, inflorescence and developing nuts. This activity greatly reduces insect numbers including insect pests. This activity also prevents the main insect pests from feeding and ovipositing on the trees. Therefore, cashew trees are well protected from a range of insect pests.

4. Can green ants encourage mealybugs, scales and aphids in cashew orchards?

It is known that green ants have a mutual association with scales, mealybugs, flatids and some species of aphids. This is because the excreta of the scales, mealybugs, flatids and aphids contain a proportion of sugar, which is good food for green ants. These honeydew-producing insects in cashew plantations are regarded as minor pests (Houston and Malipatil, 1991), but they are often seen being attended by green ants. Thus, cashew growers may concern about whether these minor insect pests will become major ones after the main pests are controlled by green ants.

To address this concern, we should consider whether the populations of these honeydew-producing pest insects exceed the economic injury level of the crop. There are a wide range of predators and parasitoids of scales, mealybugs or aphids. Our observations over the last five years showed that green ants have no significant influence on the main natural enemies of scales, mealybugs and aphids in cashew plantations (Peng et al., 1999b). These main natural enemies are ladybirds, lacewings, hoverflies and parasitic wasps (Peng et al., 1999b). When green ants are present, the minor pest insects of mealybugs and aphids are present, and predators and parasitoids of these pests are also present, resulting in very little damage to the cashew crop by these groups of insect pests.

In the literature, Chen (1962) suggested that green ants have a close association with citrus scales, the mealybugs and the flatids in citrus groves in southern China, but they do not significantly affect the activity and population size of the main natural enemies of these insect pests. A positive association between green ants and coccids in citrus is also found in southern Vietnam, but coccids have never been identified as major pests according to the interviews with many citrus growers (Barzman et al., 1996).

In conclusion, scales, mealybugs and aphids in cashew orchards with green ants are unlikely to become major insect pests.

5. How to cope with ant aggressiveness?

Aggressive behaviour is well known in green ants. Our experience over the last five years shows that green ants are aggressive to people, but their bites are not harmful, and usually the pain caused by ant bites lasts a few seconds and has no side effects after that. Normally, ants disturb people in fruit harvest of tropical fruit crops. However, this is not a problem for cashew growers, because cashew nuts are harvested from the ground under cashew trees. The only problem associated with the ant aggression is in the process of ant colony transplantation from one place to another. In this case, low-cost protective clothing has been used, and it proved to be very effective in protecting people from ant disturbance. For more information, contact R.K. Peng, Faculty of SITE, Northern Territory University, NT 0909, Australia.

6. The traditional use of green ants to control insect pests

Green ants were traditionally used in southern China for many years to control the main insect pests in citrus orchards (Chen, 1962; Yang, 1982; Huang and Yang, 1987), but their use was abandoned around 1960. In the Solomon Islands, transfers of green ant nests to control the main coconut pest insects were only temporarily successful in 1948 and 1970 (O'Connor, 1950; Brown, 1959a; Stapley, 1972), but no further application of green ants in coconut plantations has been reported since that time. The main reason is that growers could not stabilise ant populations in their orchards and they had to repeatedly introduce the ants at least once a year. These activities were more expensive than the use of insecticides at that time.

7. What was the problem associated with the traditional use of green ants?

7.1 Summary of traditional methods

First, let us look at the traditional methods of using the ants. In southern China, the ants were introduced into citrus orchards once every year (Chen, 1962; Yang, 1982; Huang and Yang, 1987; Honji Xu and Yantang Chen, Pers. comm.). After collecting ant nests from natural vegetation, collectors put them into cloth bags irrespective of source of ant nests. The numbers of bags of ant nests were transported back, and later allocated to citrus growers. The growers distributed the ant nests on some of the trees in their orchards, and then used bamboo stripes or dead tree branches to link those trees with ant nests to those which did not receive the ants. In order to prevent the ants from walking away, the growers put straw cinder on the tree trunk. It was noted that the ant population always gradually declined from May to September, and only a small proportion of the ants survived overwinter, which was too small to control insect pests the next year. Therefore, they had to repeat this introduction process every year.

In the Solomon Islands, the ant nests were cut from the original trees, and then transported to a nutfall area of coconut plantations. The nests were either placed in the crown of a palm or tied to the trunk. The palm with ant nests was connected with neighbouring palms by lines of fallen fronds laid on top of the undergrowth. After being released, green ants began to exert remarkable control of the main coconut insect pest of *Amblypelta*, but they were effective for a short period (O'Connor, 1950).

From these methods, it is obvious that in the ant transplantation process, growers created mixed populations of the ants by putting collected ant nests together from different sources, and by linking trees together irrespective of the source of the ants. Also, whether or not queen ants were included in their transplanted nests was not known.

7.2 The main behaviour of green ants

Green ants are social insects that live in colonies. The ant colonies are controlled by queens (Holldobler and Wilson, 1983; Peng et al., 1998b). According to our research, green ants show the following characteristic behaviours.

7.2.1 Within colony

- An established green ant colony often has several dozen or more than 100 leaf nests, which are spread on several or many trees, but only one nest contains a queen or queens (Peng et al., 1998b).
- Individuals of a green ant colony are friendly to each other, and they collectively forage, communicate between the nests and trees and defend the colony.
- Queens are essential to maintain colonies. Ant colonies without queens will die in about 6 months (Fig. 3).

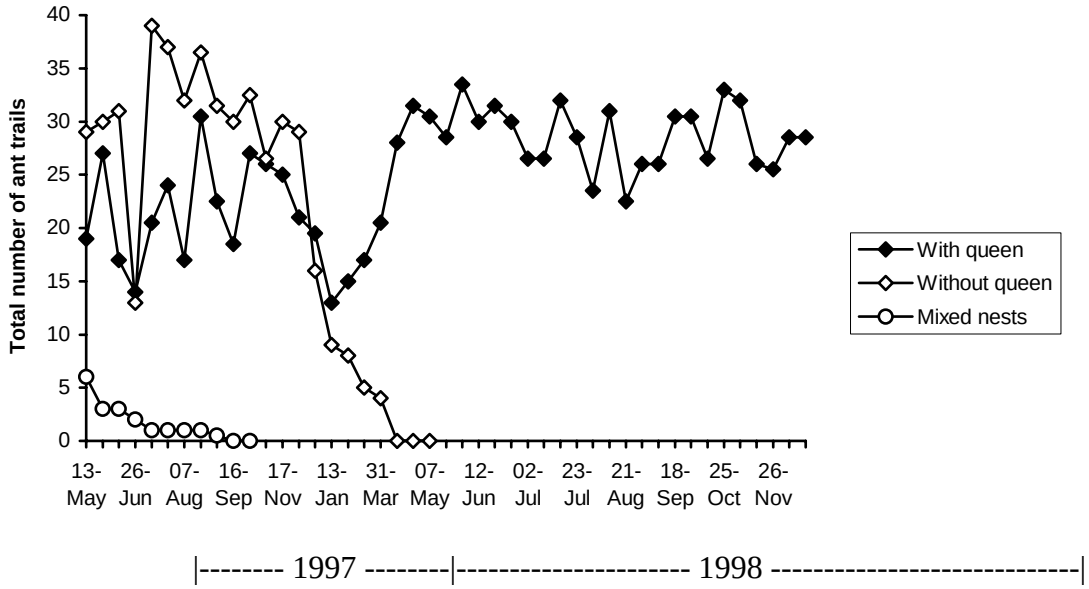


Fig. 3. The population fluctuation of transplanted green ant colonies. Data are from Peng et al. (1999b).

7.2.2 Between colonies

Green ants are strongly antagonistic between colonies (Holldobller, 1983; Peng et al., 1997c; 1998a; 1999b), and wars often start immediately after two colonies meet each other. Two green ant colonies in a garden were monitored weekly between 1995 and 1996 in the northern suburbs of Darwin. Populations of colonies 1 and 2 gradually increased from March to November 1995, and started to decline in December after two heavy rainfall events (Fig. 4, Peng et al., 1999b). In late January 1996, the two colonies met and they started to fight in February. During this time, there were four periods of heavy rainfall. These two factors combined together to cause the reduction in green ant populations of the two colonies (Fig. 4). From March to June, there were no heavy rain events, but heavy fighting between the two colonies occurred (Fig. 4). This resulted in a 50% further reduction in populations of colony 1 and a gradual increase for colony 2, because colony 2 won the battles (Fig. 4).

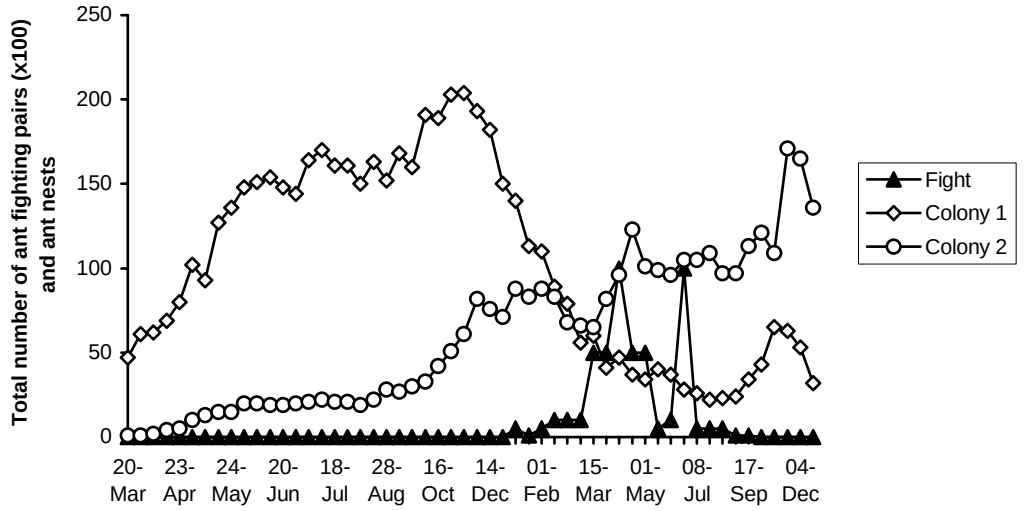


Fig. 4. Population dynamics between two well established colonies in relation to fighting frequency. Data are from Peng et al. (1999b).

7.2.3 Between green ants and other ant species

- Some species of ants compete with green ants in the field. The consequence of the competition depends on the population size and ecological requirements of ant species involved.
- Initial formation of young green ant colonies is strongly affected by the existence of well-established green ant colonies and competition with other species of ants (Peng et al., 1999b).

7.3 Consequence of the traditional method

According to these behaviours of green ants, the traditional method of transplantation of the ants resulted in

- ant fighting between colonies due to a mixed population created in the transplantation process, and
- no colony maintenance provided by queens.

Therefore, the transplanted ant populations were unstable and survived only for a short period. This is also demonstrated in our field experiments in which mixed populations of green ants without queen ants (collected from two different colonies) gradually declined and only survived for a few months (Fig. 3).

8. How to stabilise green ant populations in cashew orchards?

Long term field experiments show that the way in which the ant populations can be kept high and stable in cashew plantations is to manage the ants at the colony level (Peng et al., 1998c,d; 1999a,b). Management of green ant colonies varies with types of cashew orchards. In general, there are two types of existing cashew orchards:

- orchards with green ants; and
- orchards without green ants.

8.1 Orchards with green ants

In this type of orchard, the following five steps will keep ant populations high and stable:

- Colony identification;
- Colony management;
- Grouping of uncolonised trees:
- Transplantation of green ant colonies; and
- Monitoring and maintenance

8.1.1 Colony identification

Green ant colonies can be determined by two methods:

- following ant trails; and
- testing ants among adjacent trees.

Following ant trails

The best time to follow ant trails is between 15:00 and 19:00 hrs (dusk) because the majority of the ants during this period leave their nests for foraging and communication, and ant trails are easy to spot and follow (Fig. 5; Peng et al., 1999b).

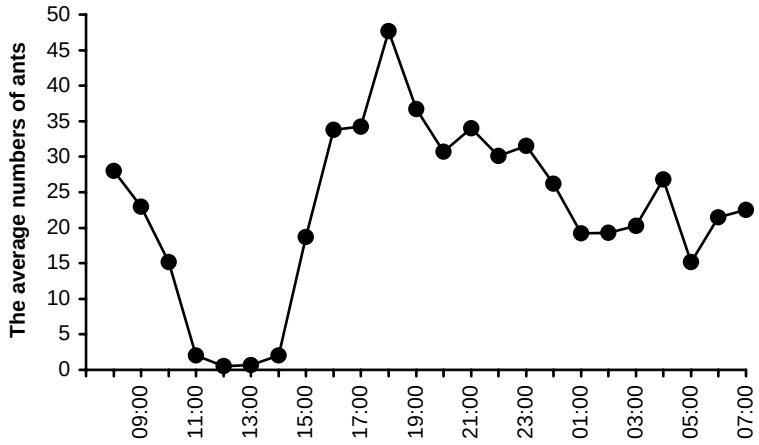


Fig. 5. The average activity of green ants during 24 hours. Data are from Peng et al. (1999b).

Green ants prefer to walk on tree branches, and sometimes they walk along the ground to other trees if no side branches connect the trees within a colony. When ants walk close to the boundary of their territory, their walking speed slows down, and they gradually stop walking. At this location, the ants posture themselves with heads towards the trail direction. Near this position, ants from another colony do the same by posturing themselves towards the ants of the first colony. A zone with no ants forms between the two colonies, establishing the 'territory boundary'. Sooner or later, this area will become a battlefield of the ants.

Testing ants among adjacent trees

This method is particularly useful for orchards with high grass between trees, where ant trails are difficult to follow. To determine whether or not trees are occupied by the same colony, small numbers of green ants are captured from one tree, and released on a neighbouring tree. If the released ants walk freely and pass the resident ants, they belong to the same colony. Otherwise, a fight will develop, indicating that they belong to different colonies.

Using these two methods, a working example of identification of the relationship of green ants between trees in a cashew orchard is provided (Appendix 1).

8.1.2 Colony management

When existing colonies are identified, florescent tapes or paint can be used to mark the colonies. If two colonies are connected to each other by interlocking tree branches, they must be separated by removing the interlocking branches. A gap of at least 1 m between the colonies should be left.
Within an existing colony, a few of the trees are often not attached to the other trees, and the ants walk on the ground in order to communicate with each other. In this case, an artificial bridge should be built to facilitate ant movement. The most cost-effective material that can be used for the ant bridges is twisted polystrings of more than 3 mm in diameter (Peng et al., 1999b).

8.1.3 Grouping of uncolonised trees

For any cashew orchard, there are always some trees which are not occupied by green ants. These trees are either close to each other or individually isolated. For an isolated tree, it can be linked by a polystring to a strong colony nearby (Appendix 2). For those uncolonised trees which are close together or nearby, they should be grouped (about 10 trees in a group) and linked with polystrings if they are not attached to each other by side tree branches (Appendix 2). Now these groups of trees are ready to receive new green ant colonies (tree groups I to V in Appendix 2).

8.1.4 Transplantation of green ant colonies

To transfer green ant colonies, a preliminary step is to identify ant colonies in the bush, and the methods for doing this have been described above (see 8.1.1). The best time of the day to transfer ant colonies is between 10:00 to 14:00 hrs because during this period the ants are least active and most of them stay in their nests (Fig. 5). The best time of a year to transfer ant colonies is between April and May (beginning of the dry season).

To carry out this work, ant-protective clothing, picking poles, buckets, large plastic bags, rubber bands and fluorescent tapes or paint are needed. Each bucket is put into a plastic bag to hold ant nests and to reduce mechanical mortality by handing and transportation, and each bucket can be filled with 5 - 10 nests depending on the size of the bucket and ant nests. Bags containing the same colony of the ants must be marked clearly on the bags when they are transported.

The final step is to release the ants. It is important to make sure that each group of uncolonised trees only receives ants from a single colony. Each tree in a group receives 5 - 10 nests depending on the size of trees and the size of ant nests. When releasing, each bag is hung on a tree branch, and then opened. Worker ants will immediately walk out to look for suitable leaves to build their new nests before they start to move brood from the old nests in the bag to the new nests. To reduce the mortality of larvae, pupae and eggs caused by deccication, it is essential to keep ant nests inside the plastic bags, and the bags should be hung in the shade of trees.

8.1.5 Monitoring and maintenance

At this point, every tree in the orchard should have green ants. The first step of using green ants has been completed, and the next step is to keep the ants on the trees. To achieve this, a program of monitoring must be set up to detect the changes of ant populations of each colony. Suggested frequency for ant population monitoring is once every 3 weeks during the dry season and once every 2 weeks during the wet season. The re-growth of the side branches between ant colonies should be continuously checked, and pruned. Ant bridges within colonies should be fixed as soon as possible if they are broken.

Through consistent monitoring, strong or weak colonies of the ants can be determined, and the causes responsible for the ant population changes can be determined. Based on our experience, if trees in an ant colony have an average of two ant trails per tree, the colony is strong. If trees in a colony have an average of one or less than one ant trail per tree or if the ants have disappeared on some of the trees in the colony, the colony is weak. There are four possible causes resulting in green ant colonies deteriorating from strong to weak:

- natural attrition;
- big rainfall;
- dispersal; and
- competition with other ant species.

Natural attrition

The average age of green ant colonies is about 7 years (Greenslade, 1971a; Peng et al., 1999b). Because the age of green ant colonies is difficult to determine at the time they are separated or introduced into the orchards, some colonies will die earlier than the others. Therefore, replacement of weak colonies is essential.

Big rainfall

During the wet season, in addition to cyclones, which are disastrous to green ants (Begg, 1977), rainfall events of > 60 mm are responsible for the reduction of ant populations (Peng et al., 1999b) because big rains break the ant nests that are built near the top of the tree where they are exposed to rain. A large proportion of the brood in the nests can be mechanically destroyed by heavy rainfall. This effect is temporary if the queen or queens in the colony survive the heavy rainfall events. In this case, the ant populations will gradually recover in a short period. However, if the queen or queens are destroyed, the colony will die in a few months. In this event, the replacement of weak colonies is necessary.

Dispersal

When cashew trees are in dormancy, they secrete very little extra floral nectar, and the trees are not attractive to a range of insects. Therefore, during this period, the trees cannot provide green ants with sufficient food, and so, the ants often walk down to the ground to forage. If the food becomes increasingly scarce, the ants start to walk long distances on the ground, and they begin to forage on other cashew trees that may already be occupied by another colony. As a result, boundary fights occur. If this happens, ground trails of the ant should immediately be cut by a heavy spray of water, and at the same time, a 5 % sugar solution and termites (or other insects) should be provided as ant food to bring the ants back (Peng, unpubli. data). During this time of year, grass and other broad-leaved weed species in cashew orchards can be very useful to the ants as foraging areas, and should be protected. To prevent the ants from walking away during times when the cashew trees are dormant, it is advantageous to mix the cashews with other species of trees or crops that have different phenology from cashews (see below).

Competition with other ant species

Based on our research, competition between green ants and other species of ants in cashew plantations in the Northern Territory is not a problem (Peng, et al., 1997a). Meat ants, *Iridomyrmex sanguineus,* lived in the same areas as green ants, and several cases of direct fighting between these two species were observed. In each case, meat ants were defeated and lost their territory because meat ants worked individually and were easily captured by several green ants. Also, meat ants nest in the ground in open areas and forage on cashew trees which grow openly, while green ants nest mostly in the thick canopy of the cashew trees and forage on more sheltered trees. Frequency of fighting between these two ant species was very low and often occurred on the edge of the cashew plantations.

Phillips (1940), Way (1953), Brown (1959a), Greenslade (1971b) and Way and Khoo (1992) reported significant competition between green ants and other dominant ant species in some areas of Southeast Asia and Africa. So far, no such strong competition has been observed between green ants and other ant species in the Northern Territory, but this competition may become a problem in the future. If this occurs in future, the use of an ant bait (for example, Amdro) is recommended to control the competitive ant species (Way and Khoo, 1992).

Based on the information provided from sections 8.1.1 to 8.1.5, a flow chart of managing green ant colonies in existing cashew orchards is provided in Fig. 6.

8.2 Orchards without green ants

There are three steps to follow to introduce green ants into orchards and to keep ant populations high and stable:

- Grouping of trees;
- Transplantation of green ant colonies; and
- Monitoring and maintenance.

These three steps have been described in detail in sections 8.1.3, 8.1.4 and 8.1.5, and they are also summarised in the flow chart (Fig. 6).

9. How long can ant colonies stay in cashew orchards after each transplantation?

There are several factors affecting the persistence of transplanted ant colonies. Theses are natural attrition, heavy rainfall during the wet season, food supply and competition with other ant species (see 8.1.5 for detail). A field experiment involving the transplantation of green ant colonies began in April 1997 at Howard Springs in order to determine how long transplanted ant colonies can persist in cashew plantations. A total of five green ant colonies with queens were transplanted onto 52 trees. Two colonies survived for **two cropping seasons** (1997 and 1998), and died in February 1999. The other three colonies persisted through **three cropping seasons** (1997, 1998 and 1999) and they were still strong by December 1999. This experiment is still on-going and the final results will indicate the average life for transplanted ant colonies. The reason for difference among colonies is, in part, due to the age of the colonies when they were transplanted. The average life of green ant colonies is 7 years old, and therefore the younger the transplanted ant colonies, the longer they can stay in cashew orchards.

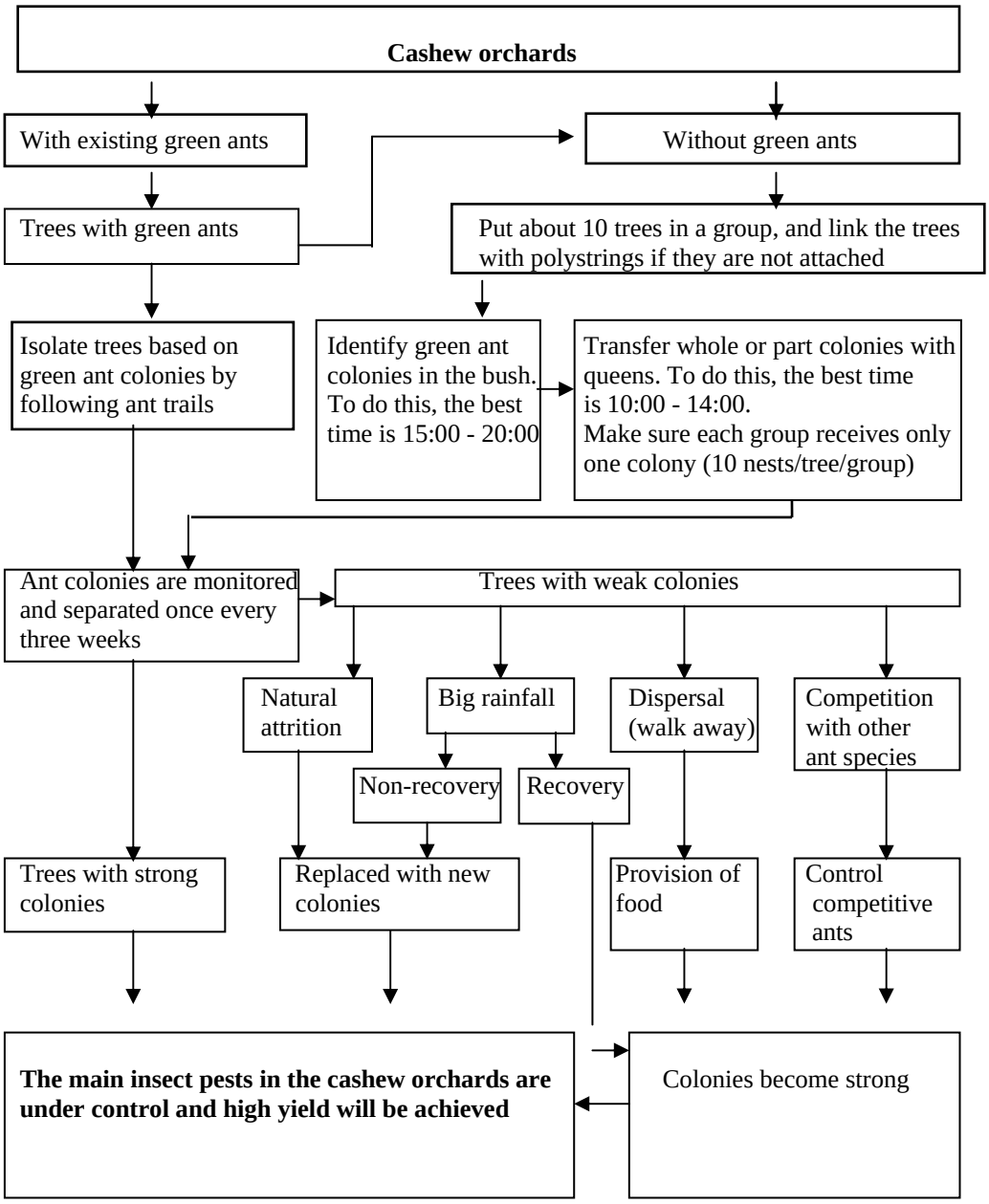
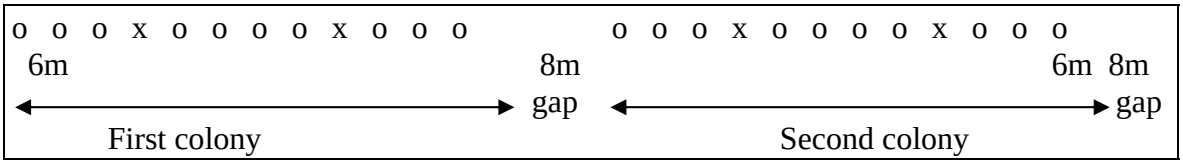


Fig. 6*. Methods of using green ant colonies in cashew orchards.*

10. How to plan cashew orchards with the use of green ants

When cashew trees are not flushing, it is difficult for them to support large populations of green ants, and some of the ants must forage on the grass and weed on the ground. Although the dormancy periods of cashews are not long (a few weeks between flushes), the ant walk-away is sometimes seen. To overcome this problem, we recommend that another tree species that has different tree phenology from cashews is planted with cashews, so that the ants can shift between cashews and the other trees depending on the food supply. Three groups of trees can be considered for this purpose: grapefruit (*Citrus* spp), black wattle (*Acacia* spp) or soursop (*Annona muricata*). Green ants live on these tree species throughout the year (Stapley, 1972; Peng et al., 1997a; Varela, 1997), and these trees have different flushing periods from cashews. In terms of the average size of green ant colonies, our recommendation is to plant 10 cashews with two trees of Citrus, Acacia or soursop (Fig. 7), and we suggest that cashew growers should manage these trees the same as cashew trees.

When cashew trees are over 2 meters high (about 2 - 3 years old), they are ready to receive green ant colonies. The procedure of transplanting green ant colonies is the same as that described in sections 8.1.3, 8.1.4 and 8.1.5.



Note:
'o' refers to a cashew tree;
'x' refers to other tree species.

Fig. 7. Layout of planting pattern of cashews with other tree species.

11. Do I need a green ant nursery?

There is no need for cashew smallholders, who usually have less than 10 ha of cashews, to set up green ant nurseries. However, for big cashew growers, green ant nurseries are important, because they can provide immediate replacement of weak colonies in cashew orchards. Based on our rearing experience (Peng et al., 1998b), the following layout is suggested for green ant nurseries (Fig. 8).

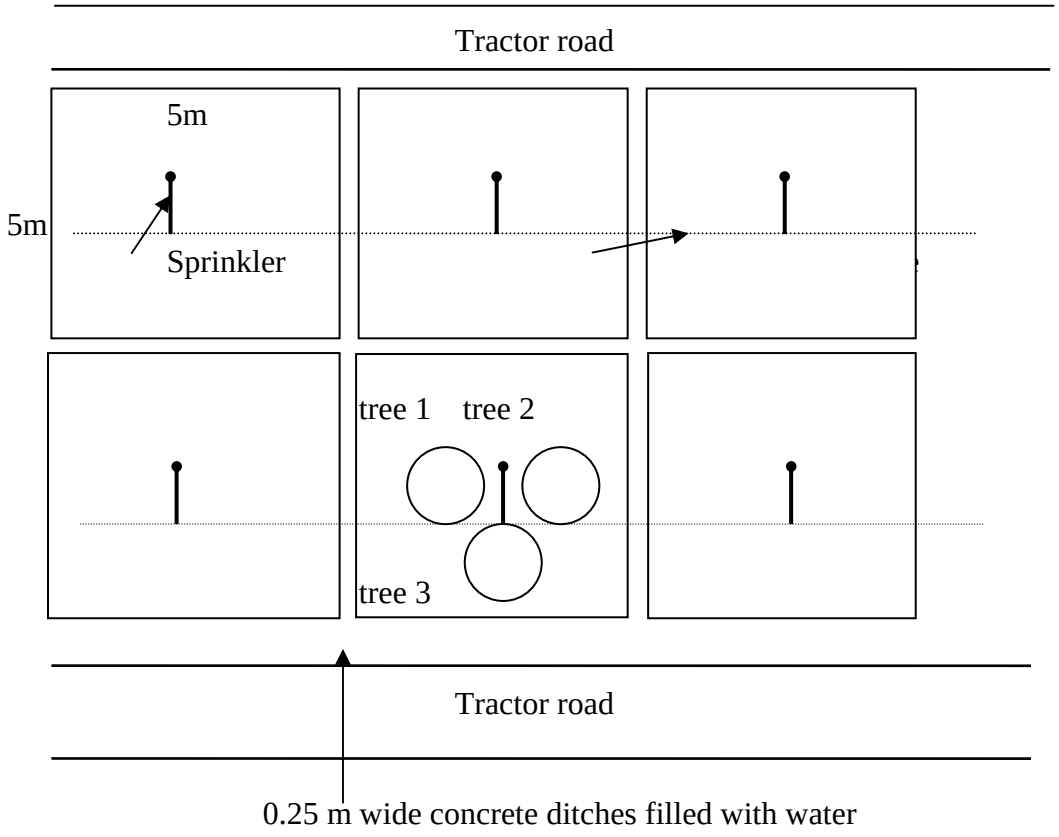


Fig. 8. Layout of an ant nursery; one colony occupying 25 m^2.

Each green ant colony occupies 25 m^2 block, which is fully separated from roads and other blocks by 0.25 m wide water ditches. The role of the ditches is to prevent green ants from walking away and to prevent other ant species from coming in. An irrigation system as shown in the diagram is necessary. Each colony will be reared on three trees of different species; tree1 can be cashew, tree 2 citrus and tree3 soursop. Each tree is planted in a giant plastic bag, which can be easily moved by tractors.

12. What is the suitable tree size for green ants to colonise?

Green ants rely on tree leaves to construct leaf nests in which they live. So, size of trees and thickness of the canopy are important. Field surveys suggested that green ants preferentially colonised trees with thick and compact canopies (Peng et al., 1997a). Trees more than two years old, which are over two meters high with some branches of compact canopy, are suitable for green ants to make successful colonies.

13. Can I rely on green ants to manage all the insect pest problems in order to produce organic products?

Yes, you can. There are two types of cashew orchards with respect to insect pest complex: type 1 which mainly suffers from bugs, caterpillars and beetles and type 2 which suffers from both type 1 pests and thrips (not including red banded thrips). For type 1 orchards, cashew growers can rely on green ants to control the major insect pests. For example, cashew orchards at Howard Springs have been mainly suffering from *Helopeltis* (bugs, Fig. 1a, b), the mango tip-borer and the leafroller (caterpillars, Fig. 2a-d) and leaf beetles (beetles, Fig. 2f). Green ants have been the only control agent used to manage these insect pests since 1996. The results showed that trees fully colonised by green ants produced higher quality nuts and yield compared with trees protected by chemical insecticides each year (Peng et al., 1999a, b). According to the literature, green ants can control over 40 species of insect pests on 12 tropical and sub-tropical crops and forest trees (Appendix 3). These insect pests mainly belong to three orders: Hemiptera (bugs), Coleoptera (beetles) and Lepidoptera (caterpillars) (Table 13). Green ants are ideal biological control agents for producing organic products in type 1 orchards.

For type 2 orchards like some at Wildman River, an IPM program which uses green ants as a major component can be made to manage the main insect pest problems. Chemical insecticides have not been used at Wildman River since the middle of 1995. Green ants have occupied most trees in every block, and they successfully control the main insect pests of bugs, caterpillars and beetles. Unfortunately, in the 1997 crop season, some patches of cashew orchards were damaged by yellow tea thrips, *Scirtothrips dorsalis* Hood. In 1998, this pest species spread so quickly that most trees in some blocks were affected.

Preliminary observations showed that these thrips mainly fed on young nuts and apples. When nuts started to set (Middle of June), the thrips appeared and fed on the area between the nut and the small peduncle. As the nut and the apple grew bigger, they moved to the surface of the nut and apple. Apples had one or more longitudinal cracks when they were moderately or seriously damaged, which resulted in poor quality of nuts. Green ants have some control efficiency on yellow tea thrips (Table 14). Although blocks with over 87% trees occupied by green ants produced significantly better quality nuts than blocks with 47% trees occupied by the ants (Table 14), they were still moderately or seriously damaged by the thrips (damage level being 10 - 20%, Table 14). This level of damage may not be acceptable by cashew growers. Therefore, it is necessary to try a range of low toxic pesticides which can be used to control yellow tea thrips without devastating green ant populations. Some natural or low toxic insecticides, such as petroleum spray oils and neem oils which are permitted for use by organic product producers, are effective to control thrips, but their impact on green ants must be assessed. In a field experiment using petroleum spray oil to control citrus insect pests, green ants did not appear to be affected by oil sprays (Andrew Beattie, person. comm.).

Table 13. Summary of insect pest species controlled by green ants. Data are from Appendix 3.

Order	Family	Number of species
Hemiptera (bugs)	Coreidae	5
	Miridae	6
	Pentatomidae	7
Coleoptera (beetles)	Chrysomelidae	2
	Curculionidae	5
	Scarabaeidae	2
	Cerambycidae	5
	Agriidae	1
Lepidoptera (caterpillars)	Noctuidae	2
	Gracillariidae	1
	Papilionidae	1
	Psychidae	1
	Geomitridae	1
Thysanoptera (red banded thrips)	Thripidae	1
Total	14	40

Table 14. Percentage damage caused by yellow tea thrips in Bore Block, 1998. Data are from Peng et al., 1999b.

Trees with green ants	Percentage damage on nuts at the level of		
	No damage	50-80%	81-100%
47%	54.6 ± 6.0 a	28.5 ± 6.0 a	16.9 ± 5.2 a
87%	70.5 ± 7.6 b	18.9 ± 5.6 b	10.5 ± 4.5 b
100%	72.1 ± 7.0 b	20.0 ± 6.0 b	7.9 ± 2.8 b

Thus, additional studies are needed to assess the influence of petroleum spray oils and neem oils on yellow tea thrips and green ants.

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Appendix 1
A working example of identification of existing green ant colonies for cashew growers, April 1997 at Howard Springs

Appendix 2
Why and how to use green ants to control the main cashew insect pests - Poster

Appendix 3. Insect pests of tropical agriculture and forestry controlled by green ants

Crop	Name of insect pest	Order / Family	Country	Reference
Tropical Agriculture				
Cassava	*Amblypelta l. lutescens* (Distant)	Hemiptera / Coreidae	Australia	Peng unpublished
	Amblypelta l. papuensis (Brown)	Hemiptera / Coreidae	Papua New Guinea	Peng unpublished
Cashew	*Helopeltis pernicialis* (Stondahl et al.)	Hemiptera / Miridae	Australia	Peng, Christian & Gibb 1995;
	Amblypelta l. lutescens (Distant)	Hemiptera / Coreidae	Australia	1997a,b,c; 1998a; 1999a,b
	Penicillaria Jocosatrix (Guenee)	Lepidoptera / Noctuidae	Australia	Peng, Christian & Gibb 1995;
	Anigraea ochrobasis (Hampson)	Lepidoptera / Noctuidae	Australia	1997a,b,c; 1998a; 1999a,b
	Nezara viridula (Fab.)	Hemiptera / Pentatomidae	Australia	Peng et al. 1999a
	Monolepta australis (Jac.)	Coleoptera / Chrysomelidae	Australia	Peng unpublished
	Amblypelta l. papuensis (Brown)	Hemiptera / Coreidae	Papua New Guinea	Peng unpublished
	Eggs of Helopeltis antonii (Sign.)	Hemiptera/ Miridae	Srilanka	Jeevaratnam et al. 1981
Citrus	*Rhynchocoris humeralis* (Thunberg)	Hemiptera / Pentatomidae	China	Chen 1962; Yang 1982; 1984 a,b
	Podagricomela nigricollis (Chen)	Lepidoptera / Gracillariidae	China	Chen 1962; Yang 1984b
	Hypomeaes sqamosus (F.)	Coleoptera / Curculionidae	China	Chen 1962
	Anomala cupripes (Hope)	Coleoptera / Scarabaeidae	China	Chen 1962
	Sympiezomia cityi (Chao)	Coleoptera / Curculionidae	China	Yang 1984a,b
	Holotrichia sinensis (Hope)	Coleoptera / Scarabaeidae	China	Yang 1984b
	Chelidonium argentatum (Dalm.)	Coleoptera / Curculionidae	China	Yang 1984b
	Papilio xuthus (L)	Lepidoptera / Papilionidae	China	Yang 1984b
	Nezara viridulu (L.)	Hemiptera / Pentatomidae	China	Yang 1984b

Crop	Name of insect pest	Order / Family	Country	Reference
	Agrilus auriventris (Saund)	Coleoptera / Agriidae	China	Yang 1984b

	Anoplophora Chinensis (Forst)	Coleoptera / Cerabycidae	China	Yang 1984b
Citrus	*Tessaratoma papillosa* (Dru.)	Hemiptera / Pentatomidae	China &Philippines	Groff et al. 1924; Leston 1973
	Rhynchororis serratus (Don.)	Hemiptera / Pentatomidae	Philippines	Garcia 1935
	Various caterpillars	Lepidoptera	Philippines	Garcia 1935
	Anoplophora versteegii	Coleoptera / Cerambycidae	Indian	Phukan, et al. 1995
	Stromatium barbatum	Coleoptera / Cerambycidae	Indian	Phukan, et al. 1995
	Inprove fruit quality		Vietnam	Barzman et al, 1996
Cocoa	*Pantorhytes biplagiatus* (Guer.)	Coleoptera / Cerambycidae	Solomon Islands	Stapley 1980
			Papua New Guinea	Friend 1973
	Amblypelta theobromae (Brown)	Hemiptera / Coreidae	Papue New Guinea	Szent-Ivany 1961
	Helopeltis theobromae (Water.)	Hemiptera / Miridae	Malaysia	Way et al. 1989; 1992
	Helopeltis clavifer (Walk.)	Hemiptera / Miridae	Papue New Guinea	Szent-Ivany 1961
	Pseudodoniella laensis (Mill.)	Hemiptera / Miridae	Papue New Guinea	Szent-Ivany 1961
	Parabryocoropsis typicus (China &Carv.)	Hemiptera / Miridae	Papue New Guinea	Dun 1954
	Pantorhytes plutus (Oberth.)	Coleoptera / Cerambycidae	Papue New Guinea	Szent-Ivany 1961
	Pantorhytes spp	Coleoptera / Cerambycidae	Papue New Guinea	Szent-Ivany 1961
	Rodents		Malaysia	Way & Khoo 1992
Coffee	Various insect pests		Sri Lankan	Leela 1961
Coconut	*Promecotheca* spp	Coleoptera	Papua New Guinea	Murry 1937
	Amblypelta cocophaga (China)	Hemiptera / Coreidae	Solomon Islands	Philips 1940; Brown 1959a;
	Axiagastus campbelli (Distant)	Hemiptera / Pentatomidae	Solomon Islands	Greenslade 1971; Stapley 1972b,
	Brontispa longissima (Gestro)	Coleoptera / Chrysomelidae	Solomon Islands	1980; Baloch 1973;
	Amblypelta cristobalensis (Brown)	Hemiptera / Coreidae	Solomon Islands	O'Sullivan 1973; Brown 1959a
	Amblypelta l. papuensis (Brown)	Hemiptera / Coreidae	Papua New Guinea	Szent-Ivany & Catley 1960

Crop	Name of insect pest	Order / Family	Country	Reference
Lychee	*Rhynchocoris humeralis* (Thunberg)	Hemiptera / Pentatomidae	China	Chen 1962
	Tessaratoma papillosa (Dru.)	Hemiptera / Pentatomidae	China	Swingle 1942
Mango	*Cryptorrhynchus gravis* (F.)	Coleoptera / Curculionidae	Indonesia	Voute 1935
	Sternochetus gravis (Fab.)	Coleoptera / Curculionidae	India	De et al. 1988
	Amblypelta l. lutescens (Distant)	Hemiptera / Coreidae	Australia	Peng unpublished
	Penicillaria Jocosatrix (Guenee)	Lepidoptera / Noctuidae	Australia	Peng unpublished
	Selenothrips rubrocinctus (Giard)	Thysanoptera / Thripidae	Australia	Peng et al. unpublished
	Various caterpillars	Lepidoptera	Australia	Peng unpublished
Oil palm	*Cremastopsyche pendula* (Joannis)	Lepidoptera /Psychidae	Malaysia	Way & Khoo 1992
	Other caterpillars	Lepidoptera	Malaysia	Way & Khoo 1992
Tea	*Poecilocoris latus* (Dall.)	Hemiptera / Pentatomidae	India	Das 1959
Tropical forestry				
Eucalyptus	*Amblypelta cocophaga* (Brown)	Hemiptera / Coreidae	Solomon Lslands	Macfarlane et al. 1976
Hoop Pine	*Milionia isodoxa* (Prout)	Lepidoptera / Geomitridae	Papua New Guinea	Wylie 1974