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Ecology and behaviour of fruitspotting bugs

G K Waite, *et al*
Queensland Horticulture Institute

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HG97010

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HORTICULTURAL RESEARCH AND DEVELOPMENT CORPORATION

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FINAL REPORT (HG97010)

G.K. Waite *et al.*
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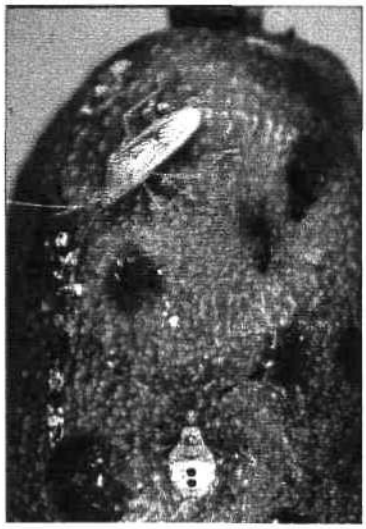


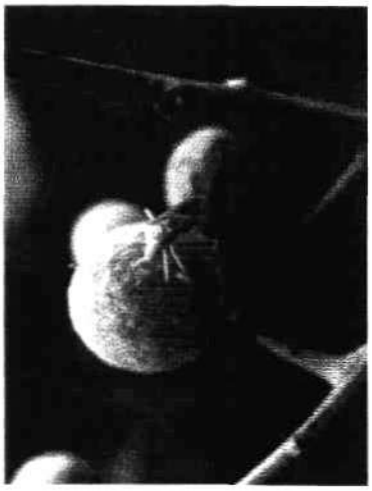
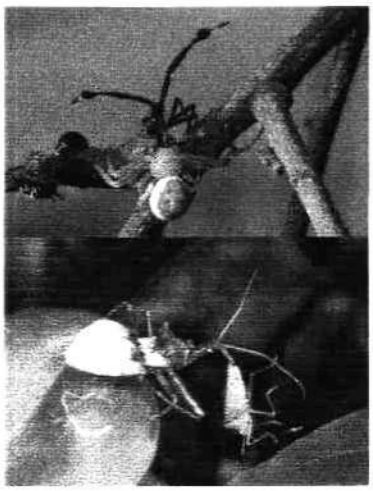


Queensland Government
Department of Primary Industries

AUSTRALIAN MACADAMIAS

AVOCADO

AUSTRALIAN GRAPE AND WINE AUTHORITY

HRDC Project Number: HG97010 - 30 June 2000

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To arrive at a long-term sustainable solution to the fruitspotting bug problem we need to develop a clear understanding of the habits of this pest - its biology, ecology and semiochemistry. For example how does it live in its natural habitat and amongst its natural enemies, what factors affect its reproduction and migration, and what are its relationships with its host plants? The answers to these questions hold the key to fruitspotting bug management. As our knowledge grows so does our ability to view fruitspotting bugs through a wider perspective that will eventually lead to the development of a multifaceted attack on the pests. This report details research conducted to try to elucidate some of the information required to develop suitable management strategies. The project was funded by the Australian Horticultural Research and Development Corporation through levy funds and a voluntary contribution provided by:

The Australian Macadamia Soc.

The Australian Avocado Growers' Assoc.

The Australian Custard Apple Growers' Assoc.

The Sunshine Coast Subtropical Fruits Association, The Tree Fruits Subcommittee of the Yeppoon District Local Producers' Association and Botanical Resources Australia also contributed funds to the research.

Research entomologists involved in the project were attached to the **Queensland Horticulture Institute,** QDPI at **Maroochy Research Station, Nambour** and at **Mareeba**, and **NSW Agriculture** at the **Tropical Fruit Research Station, Alstonville**.

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2. Media Summary

The project, 'Ecology and behaviour of fruitspotting bugs' set out to discover how these major pests of tropical and subtropical fruit crops live and behave with respect to the crops in which they are such a problem. It was undertaken to obtain information that would assist entomologists and growers to better understand how the insects utilise their many host plants and how this relates to their migration into orchards. In addition, research was conducted on some aspects of their chemical control with the uncertain future of the present control endosulfan, in mind.

As a result of these studies, the avocado industry will have access to an alternative registered chemical control in β-cyfluthrin, which will provide longer residual activity than endosulfan, which was shown to be ineffective four days after application. Because of the broad spectrum of activity of β-cyfluthrin and its longer residual effect, it is considered that its frequent use could disrupt natural enemies and lead to outbreaks of minor pests. Experiments were conducted to examine these likely effects and provide guidelines for managed use of the chemical. Behavioural and movement studies showed that the bugs continuously fly into orchards from outside breeding areas. Much of the time they inhabit certain areas that we have termed 'hotspots' and from which they move only slowly. Successive pesticide applications are likely to exaggerate the 'hotspot' effect by ensuring that most bugs don't move out of these areas before they are killed. Susceptible stages of fruit development for avocados, macadamias and custard apples were defined and the fate of damaged fruit determined with a view to using knowledge gained to develop monitoring systems.

Studies of the bugs' biology showed that the life cycle is completed in about 45 days at a constant temperature of 25°C and that *Amblypelta lutescens*, which is regarded as the more tropical of the two species studied, takes longer to develop than does *A. nitida* at temperatures ranging from 20°C to 30°C. The major natural enemies of the bugs recorded were egg parasitoids and spiders.

The conclusions were that fruitspotting bugs flying into orchards from breeding areas tend to concentrate their attack at least in the short term, on edge rows and in hotspots. These can be used for monitoring and targeted chemical control. Alternative chemical control to that offered by endosulfan is likely to cause secondary pest problems if the chemicals in question are not managed carefully. Such chemicals need to be integrated into a more rationally based system, utilising endosulfan for as long as it is available. Growers also need to monitor their orchards constantly and to carefully examine trees at all stages of fruit development to gain an better appreciation of the real extent of the damage caused by fruitspotting bugs and when the most damaging period is likely to be for individual orchards.

Future research should attempt to develop practical monitoring systems for susceptible crops especially avocados. Because of the difficulty of visually sighting the bugs, further effort should be put into research on pheromones and host plant volatiles that might lead to the development of fruitspotting bug attractants.

3. Technical Summary

The biology and mating behaviour of the fruitspotting bugs, *A. nitida* Stål and *A. lutescens lutescens* (Distant) were studied in the laboratory, using cultures maintained in constant temperature rooms at Maroochy Research Station. Feeding behaviour and its effects on fruit, and migration were studied in the field in orchards of avocados, macadamias, custard apples and longans, as well as one of their favourite alternative ornamental hosts, *Murraya paniculata*. Ecological studies in the form of seasonality of crop infestation, host relationships and habitat characteristics, orchard types and natural enemies were conducted in various orchards around the Sunshine Coast in south Queensland and on the Atherton Tableland in north Queensland. These studies confirmed the existence of edge effects and hotspots with respect to fruitspotting bug infestations, providing a possible means of exploiting that behaviour in control. They also clarified the sequence of events with respect to fruit loss as a result of bug attack, and highlighted the difficulty in detecting damage on Hass avocados.

Studies on alternative chemical control were carried out in the first instance through a series of bioassays in the laboratory at the Tropical Fruit Research Station at Alstonville, in northern NSW. The most effective chemicals identified through these experiments were tested in field trials in avocados and macadamias. β-cyfluthrin gave good control of the bugs with no negative side effects and will be registered for use in avocados. The residual activity of endosulfan against fruitspotting bugs was determined by caging bugs at various intervals post-spray on treated papaw plants. The maximum residual effect of only four days clarified why significant bug damage often occurs despite regular applications of this chemical. As a result of the review of the use of endosulfan undertaken by the National Registration Authority, its use in crops for which there was no current MRL would have been prohibited after 30 June 2000. Because of the sensitivity of the custard apple IPM system to chemical disruption of mealybug parasitoids, that industry requested work be carried out to establish appropriate MRLs for endosulfan use against fruitspotting bugs. This was carried out at Maroochy Research Station and at the Tropical Fruit Research Station at Alstonville.

In relation to IPM systems and the role that fruitspotting bugs play in those systems, any move to alternative controls for the bugs especially with respect to the chemicals used, needs to be made with the maintenance of the integrity of the whole system in mind. Because some crops especially avocados, need to be protected from fruitspotting bugs through regular applications of chemical sprays over a protracted period, it would be desirable for these alternatives to possess characteristics that allow them to be used in a way that has an outcome similar to that of endosulfan, at least with respect to their integration with biological controls. Unfortunately, the best bug-killers are also very toxic to parasites and predators. Experiments were conducted using a modified Munger cell apparatus to determine how long these deleterious effects last so that integrated programs can be developed to accommodate them. β-cyfluthrin was extremely toxic to microhymenoptera for over a month and to lacewings and ladybirds for more than two weeks. Its use will therefore need to be rationed so as not to disrupt the natural controls of scales and mites.

4. Recommendations

1. Industry should use the findings on hotspots to refine control strategies for fruitspotting bugs. The reliability and consistency in the occurrence of hotspots and their use for monitoring the bugs' presence and their targeted control, should be explored in a separate project.
2. β-cyfluthrin should be carefully integrated into IPM systems. The integration of broad-spectrum insecticides generally especially in avocados, needs to be investigated so that they are used to their optimum potential. The Bulldock® label, especially for avocados will specify a limit of a maximum of three applications per season. This means that it will have to be used in conjunction with endosulfan and should be used to moderate the perceived undesirable environmental effects of that chemical. On the other hand, to prevent undesirable side effects within the crop from Bulldock®, endosulfan sprays need to be combined with it in a way that will ameliorate these effects. Because it has longer residual activity than endosulfan, its use should probably be reserved for the periods of most intense infestation in December-January. Developments in macadamias, lychees and longans in regard to the egg parasitoid of macadamia nutborer (and this parasitoid may also be useful for the avocado fruit borer) will require fruitspotting bug sprays to be used in a way that does not compromise this natural control agent.
3. The above aspects should be investigated in conjunction with research into complete IPM systems in avocados since new approaches to fruitspotting bug control will inevitably impact on the whole system. The introduction of tebufenozide for leafroller control provides some opportunity for selective management of those pests. In addition, management of the avocado fruit borer in north Queensland needs to be integrated with that of other pests.
4. Fruitspotting bug damage in Hass avocado fruit is an issue that needs to be addressed. If field control of the bugs is poor, there is a good chance that damaged Hass fruit will find its way into the market since our research has shown that (i) not all bug damage can be seen externally (ii) growers and packers have been unaware of this fact (iii) much damaged fruit is sent to market where the damage is not manifest until the fruit ripens, usually after purchase.
5. Monitoring for the presence of fruitspotting bugs is an ongoing concern. In addition to attempts to develop a visual monitoring technique as recommended above, research should continue into the chemical ecology of the bugs. This commenced in 1990 with investigations into fruitspotting bug pheromones. All of the component chemicals have now been identified but they have not been synthesised, blended or tested. This needs to be done! In addition, **the role of host plant volatiles as mediators of both mating and food finding by the bugs should be investigated**. Observations over many years suggest that the bugs must use chemical sensors to detect and guide them to their host plants, the fruit of which is at the most suitable stage of development.

5. Introduction

Fruitspotting bugs (*Amblypelta* spp.) are the major pests of most tropical and subtropical tree fruit and vine crops grown on the coastal strip of Queensland and northern New South Wales as well as certain areas of the Northern Territory. The avocado, macadamia, papaw, custard apple and cashew industries suffer considerable losses and all of these as well as a number of other industries that are less severely affected, rate the pest as a top priority in their listing of problems to be solved. In most crops the bugs are presently controlled by the frequent application of the insecticide endosulfan, which has an uncertain future due to concerns about its suitability for such use and its potential effect in the environment. Endosulfan has been used for bug control because it is reasonably effective and generally has fewer lasting side effects on beneficial organisms in the orchard ecosystems. This means that secondary or minor pests are less likely to flare when it is used frequently, as is often required to contain fruitspotting bug infestations in some of the more susceptible areas. Other insecticides are also effective against the pests but are generally less acceptable for use in IPM systems at least at the normally recommended dosage rates and the frequency of usage necessary for fruitspotting bug control. Some might be used at lower rates, with a slightly reduced effect against the bugs being possibly countered by a reduced impact on beneficial species.

Fruitspotting bugs are Australian native insects that have adapted extraordinarily well to a wide range of introduced exotic plants, including fruit crops and many ornamentals. In addition, they utilise many native hosts and while their presence on crops and garden plants where numbers become concentrated is easily noticed and recorded, it is much more difficult to survey vast expanses of native forest in which the insects are apparently more widely scattered. For this reason, the identity and importance of many suspected native plants as fruitspotting bug hosts are not known.

Fruitspotting bugs are notorious for the seemingly disproportionate amount of damage caused to crops compared with the apparent bug population present, and also for the fact that bug presence in a crop is difficult to detect until observable damage appears. To manage an insect pest adequately it is imperative that as much information as possible is acquired concerning its life system and the environment in which it develops and lives. With such information we can begin to understand how the bugs behave and react to various environmental stimuli and orchard conditions, including the phenological stage of the crop. Until now there have been no documented field studies of the behaviour and ecology of the fruitspotting bugs, although years of *ad hoc* observations have contributed to our knowledge and form the basis for recommendations that are currently made.

Fruitspotting bugs in a world-wide perspective

The genus *Amblypelta* Stål includes fifteen species and five subspecies, several of which are serious pests of commercial fruit and nut crops in north-eastern Australia, New Guinea and some western South Pacific islands. Brown (1958a) categorised these species into three groups according to this geographical distribution. An additional three species from New Guinea and Irian Jaya have been described by Ghauri (1984).

The Australian fruitspotting bugs belong to the Order Hemiptera, Family Coreidae. Within that family, they are placed in the genus *Amblypelta*, of which Australia has two problem species - *A. nitida* and *A. lutescens lutescens* (Waite, 1990; Waite *et al.*, 1993). There is another species, A. *brevicornis*, which is distributed through inland Queensland and is not recorded as a pest yet, though it would not be surprising if at some time in the future it becomes a pest of olives, an increasingly popular crop being grown throughout its habitat range. *A. lutescens lutescens*, the Australian banana spotting bug is also present in the Torres Strait and large numbers have been observed feeding on the seed pods of *Poinciana* and the pods of a climbing bean on Murray Island (G.K. Waite, unpublished data, 1988). *A. l. lutescens* gives way to a closely-related species *A. lutescens papuensis* further north in Papua New Guinea. The literature records that this species feeds on rubber and cassava (Brown, 1958b). In Papua New Guinea it is joined by *A. theobromae*, a pest of rubber, cassava and cocoa. The numerous other species that occur throughout the region all attack at least a few food crops each. The species that causes the most problems is *A. cocophaga*. An examination of its recorded hosts reveals that it occupies a similar niche to *A. lutescens* in Queensland (Waite and Huwer, 1998). In the Solomon Islands *Amblypelta cocophaga* causes severe damage to coconuts and plantation *Eucalyptus deglupta* (Bigger, 1985).

To the west and north of Papua New Guinea, the Coreid genus of interest changes from *Amblypelta* to *Dasynus*. In the islands of Indonesia and in Malaysia, the pepper bug, *Dasynus piperis*, is a major pest of pepper (Deciyanto and Ellyda, 1989). However, one of the *Amblypelta* species, *A. manihotis*, which is common in New Guinea and feeds on cassava, also occurs in Indonesia. Other Coreids undoubtedly occur throughout S.E. Asia but there are no records of their causing problems to crops. In 1990 in southern China, a species of *Paradasynus* (probably *P. spinosus*) was collected by G.K. Waite on mock orange, *Murraya paniculata*, in Guangzhou. Mock orange is one of the favourite hosts for both of our species and it is interesting to note the similar niches colonised by related bug species in different countries. It seems that neither this species nor others that might be present in China, are pests of crops. However, that may be an illusion associated with the difficulty of accessing Chinese literature (or at least having it translated to discover what it says). The recent receipt of a translated paper from Taiwan which describes the damage inflicted by *Paradasynus spinosus* (described as the fruitspotting bug) on avocados there, and the damage described, is exactly the same as we experience here with *Amblypelta* (Hung and Jong, 1997). Avocado is a relatively new crop for Taiwan and information concerning the pests of the crop there are only now being described. Unlike *Amblypelta* spp., *P. spinosus* lays its eggs in clusters of 40-50. Aggregations of large numbers of nymphs on *Melia azadarach* (white cedar) trees are common. An undescribed egg parasitoid has been found to parasitise 40-90% of its eggs. This same bug species causes damage to citrus in Japan (S.C. Hung 1998, personal communication).

The genus *Paradasynus* also occurs in India where *Paradasynus rostratus* attacks coconuts and causes damage similar to that caused to coconuts in the Solomon Islands by *A. cocophaga* (Kurian *et al.* 1976; Ponnamma *et al.*, 1985). Populations as low as one bug per tree can cause significant damage, and typical fruitspotting bug lesions appear on the nuts (Kurian *et al.*, 1976).

In east Africa, *Pseudotheraptus wayi* is a major pest of coconuts and has been recognised as such since the early 1950s (Way,1951,1953). It was originally recorded from Zanzibar, Kenya and Tanganyika (Tanzania) (Brown, 1955) but in the 1980s, it turned up in South Africa and developed a taste for alternative host fruits (De Villiers and Wolmarans, 1980). It is now recognized as a pest of mango, avocado, macadamia, pecans and guavas in South Africa (van der Meulen and Schoeman, 1994), and will probably go on to become a problem in a wide range of hosts similar to our *Amblypelta* species, and cause the same type of damage. It attacks cashews in Kenya and was expected to increase in importance as that crop became more widely grown (Warui, 1983). In west Africa (Nigeria, Ghana and Cameroon), *Pseudotheraptus devastans* causes severe damage to coconuts if its predator, the red ant *Oechophylla longinoda*, is not present (Anonymous, 1984).

In South America, the coreid bug *Leptoglossus zonatus*, is a pest of corn (Leal *et al*, 1994) while *Phthia picta* damages tomatoes and pumpkins (Do Amaral Filho, 1981). In North America, two species of Coreids, *Leptoglossus clypealis* and *Leptoglossus occidentalis* (leaffooted bugs) are a problem in pistachios. They cause what the Americans term 'epicarp lesion' - the typical crinkled scars on the kernel and the discoloured lesions on the inside of the shell (Rice *et al.*, 1985) that we see on macadamias and pecans from *Amblypelta* spp. feeding. The leaffooted pine seed bug, *Leptoglossus corculus*, feeds on the seeds of loblolly pine and reduces seed yield.

In all of these countries, for all of the species noted, researchers and farmers face the same problems as we do in Australia. All are attempting to come to terms with how to manage highly mobile pests that breed outside cropping areas and fly in to orchards where they cause severe damage at relatively low population levels. There is general agreement amongst researchers involved with such pests that more information needs to be obtained about their ecology and behaviour.

Aims of this project

This project set out to document aspects of the biology, behaviour and ecology of the fruitspotting bugs, *Amblypelta nitida* and *A. lutescens lutescens* so that with such information, it might be possible to identify aspects of their lifestyle that could be targeted in developing an improved management system. In addition, because of the uncertainty regarding the continued availability and use of the preferred chemical control endosulfan, an undertaking was given to investigate alternative chemicals that might fulfil the requirements for fruitspotting bug management. This is especially important with respect to the impact of fruitspotting bug control on the various IPM systems employed in a range of fruit and nut industries that suffer attack from these pests.

A better knowledge of the bugs' biology, behaviour and ecology would provide the opportunity to examine ways of devising more effective monitoring and management strategies. Critical periods in the development of the fruit upon which they feed needed to be specified so that control efforts can be concentrated on these. A knowledge of patterns of movement between bug breeding areas and crops would help to determine why and how areas of noticeably more intense damage occur. In relation to this, the identity of wild host plants on which the bugs breed and from which they fly into orchards, would also be useful.

In relation to IPM systems and the role that fruitspotting bugs play in those systems, any move to alternative controls for the bugs especially with respect to the chemicals used, needs to be made with the maintenance of the integrity of the system in mind. Because some crops, especially avocados need to be protected from fruitspotting bugs for 6-7 months through regular applications of chemical sprays, it would be desirable for these alternatives to possess characteristics that allow them to be used in a way that has an outcome similar to that of endosulfan with respect to their integration with biological controls. Unfortunately, the best bug-killers are also very toxic to parasites and predators. We needed to determine how long potential control chemicals are effective against the bugs and also the extent of any deleterious effects that they may have on natural enemies. Then integrated programs can be developed to accommodate them and assist growers to better manage the whole pest complex in the respective crops.

The project has identified a number of important behavioural characteristics of fruitspotting bugs that can be used positively to improve the way the pests are managed. Of particular relevance is the confirmation of the phenomenon of edge effects and hotspots. These areas in orchards can be used to reduce the effort spent on monitoring and probably also to minimise the application and consequent cost of insecticides. When the knowledge concerning hotspots is combined with the results of the movement studies, growers can be confident that there is value in using these areas as both indicators and major control points.

Information obtained in various studies concerning chemical controls shows that good and reasonably long residual control can be obtained with chemicals other than endosulfan, but that some of these need to be used cautiously to prevent undesirable side effects. Since residual toxicity especially to small parasitic wasps that attack scale pests can exceed four weeks in some cases, the use of such chemicals needs to be carefully considered and fitted into an overall integrated system. Growers will need to accept that the use of crop scouts is the way of the future so that the best can be extracted from the pest control options that become available.

6. Survey of growers

Introduction

Fruitspotting bugs are obviously a serious pest for many growers of a variety of crops throughout coastal Queensland and northern NSW. They may also be a problem in cashews, mangoes and papaws in the Northern Territory. In order to obtain an overview of which growers are worst affected and how they perceive the pests, a survey was conducted via mail and industry newsletters. Questions were asked regarding growers' opinion of the status of fruitspotting bugs in their orchards, whether they could identify the bugs, what criteria they used for making spray decisions etc. The actual survey form appears in Appendix 1. Approximately 1600 survey forms were distributed via 'Talking Avocados', the 'Australian Macadamia Society Newsletter', 'The Custard Apple' and by direct mail. There were 207 responses to the survey, the results of which appear in Table1.

Results and discussion

Grower perceptions of pest status of fruitspotting bugs

Fifty percent of all growers of the three host crops considered that fruitspotting bugs were always a problem or an occasional serious problem. The proportion was surprisingly consistent across the crops with 56%, 59% and 50% of avocado, macadamia and custard apple growers respectively providing this assessment. Only 14 % of avocado growers (15 respondents, ten of whom were from WA, Vic. and SA), and 8% of macadamia growers considered they were never a problem, while all custard apple growers have had a problem with the bugs at some time.

Hotspots

Around 60% of all growers acknowledged that they have noted areas in their orchards where fruitspotting bug activity seemed to be concentrated, giving rise to the 'hotspot' phenomenon. Fifty percent of avocado and custard apple growers recorded edge effects but only half that number could do so for macadamias. This may be related to the greater presence of consultants and bug-checkers in the macadamia industry compared to the others and the consequent relative ignorance of individual growers with respect to the detail as to what is really happening in their crop on a week to week basis. Camphor laurel and lantana were nominated as prominent adjacent vegetation species by both avocado and macadamia growers. Neither of these two plant species has been recorded as a fruitspotting bug host. These responses would have mostly come from growers in northern NSW where these plant species are a feature of the landscape. There was no significant indication that either high points or low points in the orchard nor tall or dense crop trees were significantly more susceptible to damage than other areas and tree types, except possibly where either of these features were associated with adjacent scrub and larger hotspots.

Effectiveness of endosulfan

The verdict on endosulfan as an effective fruitspotting bug killer was mixed, with avocado growers having the poorest opinion as to its efficacy with only 36% rating it

very effective compared to 64% of macadamia growers. Again, the result is most likely associated with the more refined timing of applications to macadamias made possible by an effective monitoring procedure. This was supported by the way in which growers made decisions to spray. In avocados and custard apples, 68% and 46% respectively sprayed on a calendar basis but only 31% of macadamia growers did so.

Recognising fruitspotting bugs

One of the most surprising responses was that concerning growers' ability to identify fruitspotting bugs. Around 80% of growers of all crops claimed to be able to identify the pests, and 60% claimed to have seen the bugs in the field. It should be noted here that education of growers in this respect has been a priority over many years. Cages of live fruitspotting bugs have been exhibited at grower meetings whenever the opportunity has arisen and one would expect that gradually, growers have learned to identify them. However, our experience is that growers have a poor understanding of insect matters generally and for pests such as the elusive fruitspotting bugs, despite such educational attempts, fewer than 30% of growers would be able to identify them in a 'lineup' where comparisons with other insects are possible. Isolated insects with no reference for comparison in the field would reduce that level of competence considerably.

The survey provided some useful insights into growers' understanding of the fruitspotting bug problem and their responses to it. It confirmed some of our notional ideas regarding hotspots and the effectiveness of endosulfan, as well as attitudes to monitoring amongst the various industries. These issues were already on the project agenda and the information provided by the survey confirmed that they required more detailed study. The results of those studies are reported in the appropriate sections.

Table 1. Results from the survey - 207 respondents and results expressed as percentages

FSB status in your orchard:	**Avocados**	**Macadamias**	**Custard apples**
Never a problem	14 (15/108)	8 (3/39)	0
Minor problem	29 (31/108)	28 (11/39)	50 (7/14)
Occasional serious problem	24 (29/108)	33 (13/39)	43 (6/14)
Always a problem	32 (35/108)	26 (10/39)	7 (1/14)
Cultivars	16 Fuerte 37 Hass 40 multiple cvs	Insufficient data provided	NA
FSB 'hotspots' noted	56 (60/108)	62 (24/39)	64 (9/14)
Edge Effects?	53 (57/108)	26 (10/39)	50 (7/14)
Surrounding vegetation	20 (21/108)	10 (4/39)	
Adjacent vegetation	47 (51/108)	41 (16/39)	
Type of vegetation	12 Lantana 5 Camphor laurel 19 Rainforest	Camphor laurel Lantana	
High points	18 (19/108)	13 (5/39)	
Low points	13 (14/108)	13 (5/39)	
Sheltered	24 (26/108)	18 (7/39)	
Dense	15 (16/108)	15 (6/39)	
Tall	14 (15/108)	n/a	
Tall/dense	13 (14/108)	18 (7/39)	
Effect of endosulfan			
Useless	1 (1/76)	0	0
Variable	9 (7/76)	4 (1/28)	17 (2/12)
Moderately effective	54 (41/76)	36 (10/28)	42 (5/12)
Very effective	36 (27/76)	64 (18/28)	42 (5/12)
Any residual effect from endosulfan	4 (4/108)	3 (1/39)	7 (1/14)
Combined with copper sprays	40 (43/108)	23 (9/39)	29 (4/14)
Other chemicals used	11 (12/108)	8 (3/39)	1
List other chemicals used	Chlorpyrifos (3) Dimethoate (2) Trichlorfon Methidathion B-cyfluthrin Carbaryl, Pyrethrum	B-cyfluthrin Acephate Methidathion (not as effective as endosulfan)	Methidathion
Ability to identify FSB	85 (92/108)	82 (32/39)	79 (11/14)
Have seen FSB in field	58 (63/108)	59 (23/39)	64 (9/14)
Sprays are applied:			
Calendar	68 (51/75)	31 (9/29)	46 (6/13)
See damage	24 (18/75)	41 (16/29)	54 (7/13)
See bugs	8 (6/75)	10 (3/29)	0
If by calendar - timing	from 7-10 days to monthly (18/51 fortnightly)	from 2-5 weeks to twice/season	from fortnightly to once a year
Basis for spray decision if not calendar			
First sight	43 (17/40)	38 (9/24)	
Indicator trees	15 (6/40)	4 (1/24)	
Odd fruit damaged	18 (7/40)		
Several fruit damaged	13 (5/40)		
Other measures	3 (1/40)	58 (14/24)	
Respondents			
NSW	25 (27/108)	87 (34/39)	
QLD	66 (71/108)	13 (5/39)	
Other states	5 WA, 4 Vic, 1 SA		

7. Biological studies

7.1 Biology

7.1.1 Fruitspotting Bug Laboratory Culture

A regular and constant supply of adults, nymphs and eggs was produced by the laboratory culture to permit the conduct of various experiments that included life cycle studies, behavioural observations and chemical testing. Rearing the bugs was time-consuming and frustrating at times because of the high nymphal mortalities that often occurred, but it is still more efficient and reliable than attempting to collect large numbers of bugs from the field.

Both the fruitspotting bug, *Amblypelta nitida*, and the banana-spotting bug, *Amblypelta lutescens*, were maintained in laboratory culture for the duration of the project. They were reared in clear plastic containers under ambient-temperature conditions in an outside insectary during the warmer months, and moved to a controlled-temperature room (65%RH and 25°C) during winter. Absorbent paper towel was laid on the base of the containers to absorb the liquid faeces and moisture was provided for the bugs via dental wicks partially immersed in sterilised water. The watering containers were made from plastic 100 ml Solo® cups that were closed with a water-tight lid. A cross-shaped cut in the lid allowed the dental wick to be pushed through it and into the water inside. French beans that had been washed in clean water with detergent to remove any possible chemical residues, were provided as the staple diet, since they were readily available all year round from the supermarket. Additional food was supplied when it was available according to species preferences. These included mock orange, guava, longan, avocado and macadamia fruit, and papaw tips. The bugs were provided with fresh food twice weekly and their cages were thoroughly cleaned or changed once a week. The adults were stored in groups of 20 bugs, 10 male and 10 female, per container and any eggs that they produced were collected and placed into smaller plastic containers. When these eggs hatched and the young nymphs moulted from 1st to 2nd instar they were moved into the large plastic containers and reared to adults.

7.1.2 Life cycle parameters

Methods

Eggs and nymphs produced by the laboratory culture were used to determine various life-cycle parameters and to study the mating behaviour of the adults. The development time for immature stages of each species at three constant temperatures was studied using a constant temperature incubator. The number of eggs and nymphs on which the observations were made are shown in Table 2. These varied according to their availability at the time. Usually, the nymphs that hatched from the egg treatment were followed through to maturity but in some cases, extra individuals were included at the first instar stage to accommodate expected mortality of later instars. Nymphs were placed into individual ventilated vials and fed with portions of green bean. The time occupied by each instar was calculated from the date of each moult. These were recorded during observations made twice a day at about 9.00am and 4.00pm.

Table 2. ***Amblypelta nitida*** **and** ***Amblypelta lutescens*** **development times (in days) at three constant temperatures (n = number of insects of each stage moulting at each temperature)**

Stage	*A. nitida*			*A. lutescens*		
20°C	**n**	**Range**	**Mean**	**n**	**Range**	**Mean**
egg	55	11-16	13.2	71	11-21	15.5
1st	82	3-6	4.3	84	3-9	4.2
2nd	32	6-30	11.8	16	7-17	11.8
3rd	31	5-25	9.1	16	6-25	15.2
4th	31	6-21	10.4	15	9-26	16.6
5th	31	9-23	14.5	15	10-22	15.1
2nd-adult	31	27-66	45.8	15	41-75	58.7
egg-adult			**63.3**			**78.6**
25°C						
egg	28	6.5-9.5	7.5	67	8-10	8.2
1st	58	2-4	2.8	53	2-5	3.1
2nd	55	5-33	9.9	50	5-21	9.2
3rd	55	4-16	8.0	50	3-37	8.1
4th	55	3-13	7.3	48	2-12	8.6
5th	54	7-14	9.7	48	6-17	12.5
2nd-adult	54	27-48	34.9	48	26-59	38.4
egg-adult			**45.2**			**49.7**
30°C						
egg	64	5-7	5.4	87	5-7	6.0
1st	21	2-3	2.8	29	2-2.5	2.4
2nd	8	4-12	6.5	14	6-15	8.5
3rd	8	3-7	4.8	14	6-17	9.8
4th	8	3-7	4.3	14	3-18	7.5
5th	8	3-8	5.7	14	5-10	6.7
2nd-adult	8	16-29	21.3	14	23-41	32.5
egg-adult			**29.5**			**40.9**

Results and Discussion

With regard to the following discussion concerning the environmental adaptations of the two species, it is somewhat surprising to note that at all of the constant temperatures under which the bugs were reared in this study, *A. nitida* matured faster than *A. lutescens*. *A. nitida*'s advantage was apparent in almost every stage and at all temperatures. As the temperature increased, the development rate of both increased. The interesting result is that at 30°C when the what has been considered the more tropical species, *A. lutescens*, might be expected to do better than *A. nitida*, the difference in the developmental rates was greatest, and favoured *A. nitida*. From these data we can now confirm that in summer a generation is completed in about six weeks.

7.1.3 Laboratory egg production and its relationship to bug activity in the field

In conjunction with the fruitspotting bug laboratory cultures, 15 pairs of each *Amblypelta* species were kept at ambient conditions all year round, for three years. As

mates died they were replaced. The eggs that were produced were collected initially twice a week and then once a week, and the average egg production per female per day was calculated to provide an insight into the biological sequences that occur as the seasons change. As is evident from Figure 1, fruitspotting bugs dislike extreme temperature conditions and their egg production dropped accordingly – this was most evident during mid-summer and mid-winter. Egg production cycles fitted well with day-length variation (Figure 1). The average daily temperature graph would mirror that for day-length. Since the day-length pattern mirrors mean temperature variations during the year it is apparent that egg production virtually ceases during winter when overall fruitspotting bug activity also declines. *A. nitida* laid more eggs earlier in the 'season', coming out of winter than did *A. lutescens*, but overall egg production of *A. lutescens* after the weather warmed up, was greater.

These characteristics of the two species are not entirely unexpected when their natural geographic ranges are considered. Despite the interesting data on development rates at various temperatures, *A. lutescens* does seem to be more attuned to tropical conditions than is *A. nitida* and shows its tropical affinity by merging into the geographic range of *A. lutescens papuensis* in the Torres Strait. Although *A. nitida* is known to occur as far north as Iron Range it does not appear to be as common as *A. lutescens* in that environment. Indeed, along the southern Queensland coast *A. nitida* becomes very scarce at latitudes north of Gympie, but studies conducted in this project have shown it to be quite common in parts of the Atherton Tableland where the altitude probably modifies the climate sufficiently to its liking. On the other hand, it is better adapted to the cooler subtropical environment than is *A. lutescens*, which has still not been recorded south of Brisbane. *A. nitida* on the other hand, has been recorded as far south as Sydney.

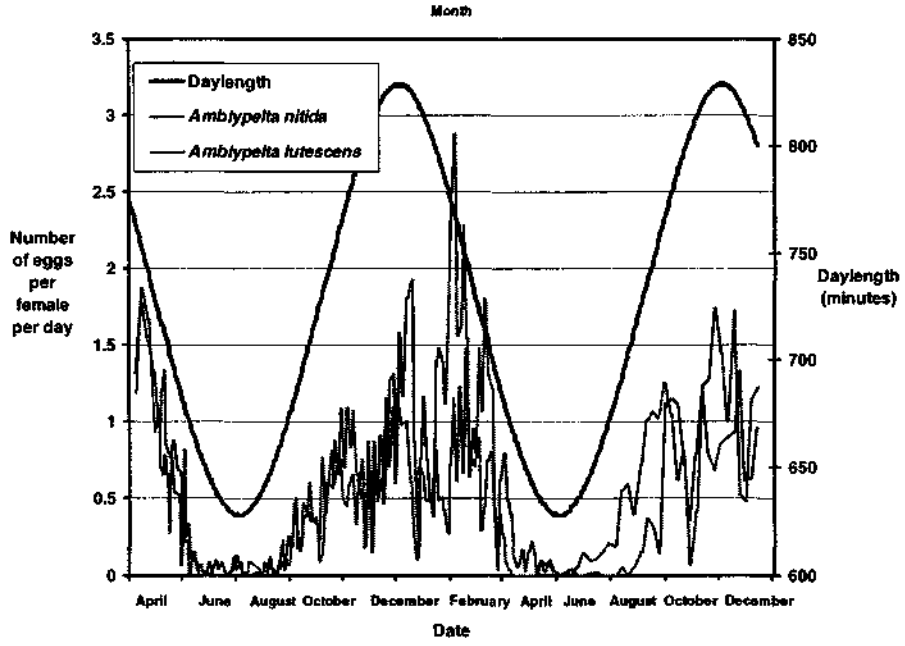


Figure 1: Day-length and the average number of eggs laid per female per day under ambient conditions at Maroochy Research Station for one seasonal cycle between February 1998 and February 2000.

7.1.4 Reconciling potential egg production with observed populations in the field

Fruitspotting bug eggs are laid singly on various plant parts, usually on leaves. In contrast, many common bug pests notably Pentatomids such as *Nezara viridula*, the green vegetable bug, lay their eggs in rafts comprising up to 70 eggs. A female fruitspotting bug may lay a number of eggs singly in a certain portion of a tree, with the resulting nymphs tending to eventually aggregate on the same fruit or panicle. This aggregation often becomes more pronounced in lychees and longans as ripe fruit is harvested, or
damaged fruit gradually drops off the tree leaving fewer sources of food for the flightless nymphs forcing them to gradually gravitate to the fruit that is left.

In our studies we encountered parasitised eggs infrequently in the field, although that is largely a reflection of the overall frequency of finding fruitspotting eggs of any description because of their colour and scattered distribution. Fay and Huwer (1993) reported three parasitoids attaining combined parasitism rates of up to 91.6% in the eggs of *A. lutescens* in north Queensland. Other studies in southern Queensland indicated that similar parasitism rates occur there through the agency of at least two parasitoids, a *Gryon* sp. and an *Anastatus* sp. (Waite and Petzl, 1997). As with similar host parasitoid relationships, because the parasitoids rely on the presence of host eggs to reproduce and their numbers are low coming out of winter, parasitoid numbers and hence parasitism rates, lag in relation to the host. These rates increase as the season progresses and may be the reason for the number of nymphs noted on unsprayed lychees and longans as well as on *Murraya paniculata*, generally not equating with what might be expected from the number of adult bugs frequenting those plants.

For example, a female bug may lay up to three eggs a day on average. If she stayed in the same tree for five days then theoretically there should be about 14 nymphs present on that tree, allowing for a 90% hatch rate excluding egg parasitism or predation. These nymphs would become visible on the tree by the time they reached the third instar. Observations made on unsprayed longans at Maroochy Research Station show that such numbers never eventuate and the result is even more striking when the total number of female bugs observed over time on those same plants is considered ie. few nymphs were produced and/or survived relative to the number of female bug days spent on a tree (Table 3 & Figure 2).

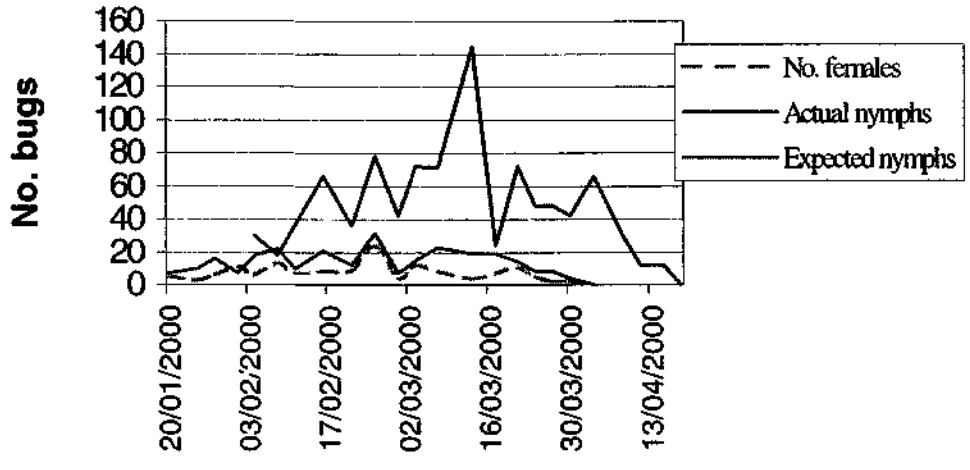
The data show that the average nymph production/survival was about 1.8 per female over the whole of the period assessed (Table 3). This is less than the three that might be expected if all of the adult bugs stayed only one day each, whereas the expected production figures were calculated on an average of two full days' presence per female over the observation period. On each assessment date all of the adults and nymphs that were visible were caught and removed from the trees. Successive assessment dates were 4-5 days apart. Adult bugs apparently fly into and out of an orchard on a daily basis (see Mark/recapture Section) so that probably half of those caught on each occasion would have been present for at least two days and some for three or four days. The calculated figures are thus considered to be very conservative. The figures for the expected number of nymphs have been brought forward 15 days from the commencement of observations since this is the time it would take for nymphs to reach the third instar and become visible. There is an expectation that the production of nymphs should be much higher than was observed, and that mortality factors that operate on the eggs and perhaps the early instar nymphs are accounting

for a significant proportion of the fruitspotting bug population and thus regulating numbers.

Table 3: Number of fruitspotting bugs, A. nitida, females and nymphs on longans at Maroochy Research Station in 2000.

Date	Female bugs	Nymphs actual	Nymphs expected
20 January	5	7	-
25 January	3	10	-
28 January	6	16	-
1 February	11	7	-
4 February	6	18	30
8 February	13	22	18
11 February	7	10	36
16 February	8	21	66
21 February	9	12	36
25 February	24	32	78
29 February	4	7	42
3 March	12	15	72
7 March	8	23	71
13 March	4	19	144
17 March	7	19	24
21 March	11	14	72
24 March	5	8	48
27 March	2	8	48
30 March	2	4	42
3 April	0	0	66
8 April	0	0	30
11 April	0	0	12
15 April	0	0	12
18 April	0	0	0
Total	**152**	**279**	**947**

Figure 2: Actual number of A. nitida nymphs recorded on longans compared with the expected number in relation to females present



7.1.5 Mating behaviour of fruitspotting bugs

Except for unsprayed situations, all adult fruitspotting bugs that are found in commercial orchards develop and mature in habitats outside of the orchard. These habitats may be natural forest areas that contain an abundance and variety of plant hosts, or they may be urban gardens that also contain a variety of alternative, generally exotic ornamentals and fruit trees that are sprayed infrequently or not at all. While mating pairs of fruitspotting bugs can commonly be seen in orchards that have not been sprayed the majority if not all, of immigrant females have already mated when they enter an orchard and hence are able to lay viable eggs immediately.

To document the mating behaviour of each species, courting bugs were observed in the laboratory. The prelude to mating in both species is seen as an approach to the female by a male, which begins stroking the female with its antennae and legs. This appears to be a pacifying gesture to coax the female to remain passive and submissive so that the male can mount and copulate. If the initial advances by the male are successful mating occurs within a relatively short time, usually within minutes. However if the female is not receptive at the time, she discourages the male with kicks of her legs and moves off to another resting place.

During copulation the male of *A. nitida* climbs on top of the female and remains there with his body parallel but slightly to one side of the female. In order to uncouple, the male must turn to face in the opposite direction to the female and pull away. In contrast, males of *A. lutescens* mount the female in the same way as for *A. nitida*, but they immediately turn around to face the opposite direction, remaining in this position for the length of the mating session (Plate 1). That time may last from 30 minutes to several hours for both species.

Plate 1. *A. lutescens* mating position with other attentive bugs

Also evident in Plate 1 is the interest shown in the mating pair by other bugs. Even though this photograph was taken in one of the laboratory rearing containers, there was a definite aggregation that seemed to be initiated by this pair's mating activity. Quite often when mating couples were encountered in the field, they were attended by one and sometimes two or three other males. This suggests and probably confirms that attractive chemicals, which may be pheromones or kairomones, are involved in bringing the sexes together for mating. If as previous research has suggested, the male is responsible for attracting the female, other males may also be attracted by the pheromone or perhaps other allelochemicals on the off-chance that more than one female will have responded to the original male caller. Insects produce a range of chemicals known as kairomones that may attract one or both genders of the same species and their natural enemies. They may also be emitted by either sex. On unsprayed host trees and especially in lychee and longan orchards that are not sprayed, significant numbers of fruitspotting bug nymphs may develop. In these crops, because the fruiting panicles are borne on the outside of the tree canopy, the bugs feeding on them are more visible than in most other crops. It was common for aggregations of several nymphs as well as additional males, to be found in association with mating pairs. All of these factors point to chemical cues being involved in the mating process. For some other bug species especially *Nezara viridula*, the green vegetable bug, such chemicals have been shown to attract parasitoids of both the eggs and adults (Aldrich 1988, 1995; Aldrich *et al.* 1991; Bin *et al.* 1993). It is presumed that the egg parasitoids of *Amblypelta* spp. also respond to kairomones produced by the female bugs when the eggs are laid.

Laboratory observations indicate that females need to mate several times during their life to maintain continuous production of viable fertilised eggs. Both males and females were recorded mating up to seven times, but this was in confined spaces with both sexes continuously in one another's presence. In the field where some effort has to be expended in mate-finding and courting, the total number of matings may be significantly fewer. Without repeated matings females eventually lay unfertilised eggs. Females are generally ready to mate at about five days after the final moult to adulthood and continue to mate after two or three months of age in the laboratory. The average life expectancy of an adult bug in the wild is not known but in summer when hazards presented by natural enemies and adverse weather are probably more common, individuals may not live for more than two months. It is expected that females would be capable of continuous egg laying during a two-month life. On the other hand, in the absence of natural hazards when reared in the laboratory, the bugs may be quite long-lived with some actually living for more than 12 months.

7.2 Natural enemies of fruitspotting bugs

Although there are several natural enemies of fruitspotting bugs with which we are familiar, none are capable of reducing bug populations to levels low enough to prevent excessive damage to susceptible crops. As a result, the use of insecticides remains the most economically viable management option within orchards at this time. However, there may be some opportunities to manipulate the natural habitat and general landscape to benefit them and enhance there effect, a technique known as conservation biological control.

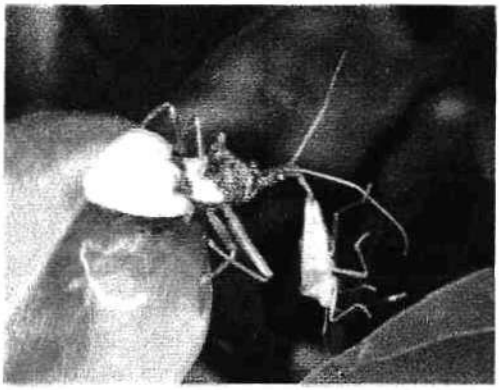


Plate 2: *Pristhesancus maculipennis*, an assassin bug, feeding on a fruitspotting bug

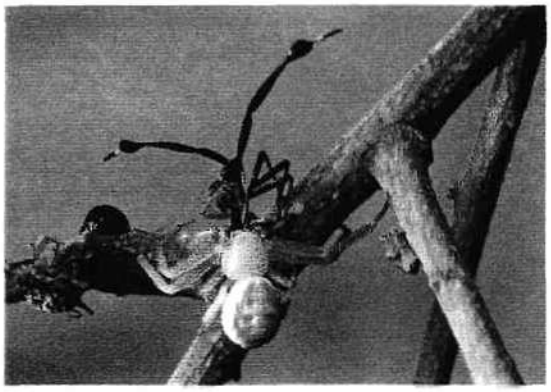


Plate 3: A crab spider attacking a third instar fruitspotting bug nymph

Natural enemies of insects include predators (Plates 2 &3), parasitoids (Plate 4) and pathogens and under the right conditions they will suppress a pest population and make it less damaging. Fruitspotting bugs do have a number of natural enemies, and while they may appear to have little impact on the population dynamics of the pest, we can be sure the fruitspotting bug problem would be much more severe if they were not operating. A major problem for the natural enemies of fruitspotting bugs is the bugs' mobility. They breed in scrub and forest areas or on alternative ornamental hosts and backyard fruit trees from which they continually fly into orchards. Although they seem not to fly very far and often stay in the same place for variable periods of time, they still tend to move around quite a lot. Most of the natural control will occur in the unsprayed areas that are relatively biologically stable. In fact egg parasitism rates later in the season may reach very high levels, perhaps in the order of 70-80%. By this time though, most of the bug damage to crops has been done and many of the host fruit crops are past their phenologically susceptible stage. Nevertheless, the activity of these natural enemies during mid to late season ensures that the number of over-wintering bugs is much lower than would otherwise be the case.

Plate 4: *Gryon* sp. emerging from fruitspotting bug egg

In addition to the mobility of the adults both they and the nymphs possess very effective chemical defence weapons in the form of odour glands, the contents of which are directed at anything that might pose a potential threat. Ants, spiders and

assassin bugs are among some of the more important fruitspotting bug predators and ants, especially the green tree ant, *Oecophylla smaragdina*, in tropical Australia and the Pacific Islands, are regarded as very important predators of fruitspotting bug species that are pests of coconuts, cashews and mangoes (Brown, 1959; Peng *et al.*, 1997a,b). These predators are all generalists and will feed on anything they can catch.

Parasitoids on the other hand have the potential to be more effective since they are generally more selective. Some parasitoids are quite specific, often targeting only one host species. The egg parasitoids that have been reared from fruitspotting bug eggs probably range across a number of bug species, but can still provide a good level of control. Fay and De Faveri (1997) reported the three species of parasitoids like those figured below, attacking the eggs of the banana-spotting bug, *Amblypelta lutescens* in north Queensland.

Plate 5: Egg parasitoids of dasynine bugs (from Phillips, 1941)

***Anastatus* sp.**
(Eupelmidae)

***Gryon* sp.**
(Scelionidae)

***Ooencyrtus* sp.**
(Encyrtidae)

Previous studies and those conducted during the course of this project revealed that a similar group of parasitoids attacks both species of *Amblypelta* in southern Queensland (Waite and Petzl, 1997).

In a series of glasshouse experiments carried out at Mareeba, it was found that *Anastatus* sp. was the most effective of the three, parasitising up to 84.4% of bug eggs placed experimentally. Increasing the number of bug eggs, releasing larger numbers of *Anastatus* sp. or caging adult bugs in the vicinity of the deployed eggs enhanced parasitism levels. Small-scale field releases of *Anastatus* sp. resulted in negligible parasitism but when pairs of adult bugs were confined with the deployed bug eggs, parasitism levels increased to between 22% and 50%. This suggests the parasitoids may be using the chemicals including pheromones produced by the fruitspotting bugs as kairomones ie. host-finding cues. For *Anastatus* sp. to be utilised as a control agent or integrated into existing control systems more research would be required to overcome the problems associated with mass rearing. Massive numbers would be required to flood the natural breeding areas of the bugs and have any impact on fruitspotting bugs that fly into orchards. Because they are relatively specific, such an operation would require the production of millions of bug eggs to breed the parasitoids.

8. Fruitspotting bug movement patterns - immigration and intra-orchard movement

Introduction

Amblypelta spp. are known to have a considerable host range (Waite and Huwer, 1998), but virtually nothing is known of how far individual bugs move between host plants, how often they move between orchard trees or hosts, and how long they live in the field. This information is pertinent to crop situations, as its acquisition would help to elucidate where fruitspotting bug pest populations originate (native bush, other crops or hosts, urban backyards or certain ornamentals), and how these populations develop during the season and are sustained in crops. For some time it has been known that trees in crops bordering areas of scrub or forest often suffer substantially higher levels of bug damage than trees more remote from crop edges (Waite *et al.*, 1993; Ryan, 1994). The fact that these areas are near the edges and close to their breeding areas is not coincidental. It merely reflects the pattern of migration, which apparently is initiated in the first instance because there is a food source there. Once in the new orchard habitat, the opportunity for finding a mate as well as food, arises.

This partly contradicts a view that bugs fly considerable distances, suggesting rather that they make short flights between hosts or between refuges and hosts. If bugs are relatively sedentary, then damage in crops may be more likely confined to a few trees or areas of an orchard (hotspots), and a more targeted approach to control adopted based on monitoring. However, should bugs within a crop change feeding location frequently and egg laying be widely dispersed as a result, bug damage would occur throughout the crop with fewer possibilities for targeted control. Some of these issues were investigated in the research described below, using mark-recapture techniques in the absence of any means to trap bugs. As such, these studies had to be undertaken in host plants which facilitated the observation and capture of bugs. The two experiments undertaken in north Queensland involved the ornamental host, *Murraya paniculata*, mock orange, and a papaw crop surrounded by macadamias, mangoes, cashews and carambolas, which are also fruitspotting bug host crops. In south Queensland, *M. paniculata* was also used as well as longan.

8.1 North Queensland

Methods

Studies in mock orange – Mareeba.

Studies were conducted from October to January in two large clumps of mock orange that were about 75 m apart, with a section of a building, a car park and miscellaneous non-host ornamental trees situated between them. Adult bugs, *Amblypelta lutescens*, were marked with various colours of liquid paper (Tipp-Ex®) applied to the pronotum. Six bugs captured in the mock orange at Site 1 were marked and released at the same site, along with 20 laboratory-reared bugs marked with a different colour. Eight bugs captured in the mock orange at Site 2 were marked and released at the same site, along with 20 laboratory-reared bugs marked with a different colour. Different colours were also used for the Site 1 and Site 2 bugs.

A search of 30 minutes' duration was conducted every week over the study period, and all the bugs (marked adults, unmarked adults and nymphs) visible in the clumps of mock orange were recorded. Unmarked adults were caught, marked with the same colour as the original 'wild' bugs, and released back into the same bush so that the number of marked bugs increased through the study. Nymphs could not be marked as the colour would have been lost at moulting.

Studies in papaws – Walkamin

Adult bugs, mainly males, were accumulated over a week or so from a colony of *A. lutescens* held in Mareeba. When the collection numbered 100 adults, small coloured plastic discs with individual numbers inscribed on them were glued to the pronotum of each. Five different coloured discs were used to label 20 bugs for each colour, to allow five different release points to be used in the experiment. The bugs were placed in cages according to their colour group and transported to Walkamin Research Station. The five groups of bugs were released in blocks of either papaws (750 mature plants in two blocks), macadamias (40 trees), mangoes (60 trees) or carambolas (50 trees in two blocks), or in a patch of eucalypt scrub, as shown in Figure 3. Therefore, a single colour represented a particular release point.

Monitoring for the released bugs was undertaken only in the two blocks of papaws, and commenced the day after the bugs were released. This was repeated over the next three days and then occurred weekly over a seven week period in April and May. All 750 papaw plants were examined on each occasion, and the presence of all unmarked adults and nymphs was recorded along with the released bugs. This allowed the changing pattern of bug presence on each papaw plant to be described over the monitoring period. Movement of released bugs within the papaw crop could also be tracked over time.

Results

Mock orange - Mareeba

Numerous marked bugs were observed in the mock orange over the period of the study but with the marking system used, it was not possible to identify the date on which each 'wild' bug had been marked. Hence the actual period of time spent by these bugs at the one site could not be calculated (Figure 4). However of the laboratory-reared bugs recaptured, one was recorded six weeks after its original release. Only one bug was found to have moved between the two clumps of mock orange over the entire sampling period (Figure 4).

The total number of 'wild' bugs marked ie. those detected, caught, marked and released *in situ*, was greater than would have been expected to mature from the number of nymphs recorded over the same period. This indicated continuous immigration into these favoured host plants from outside breeding areas.

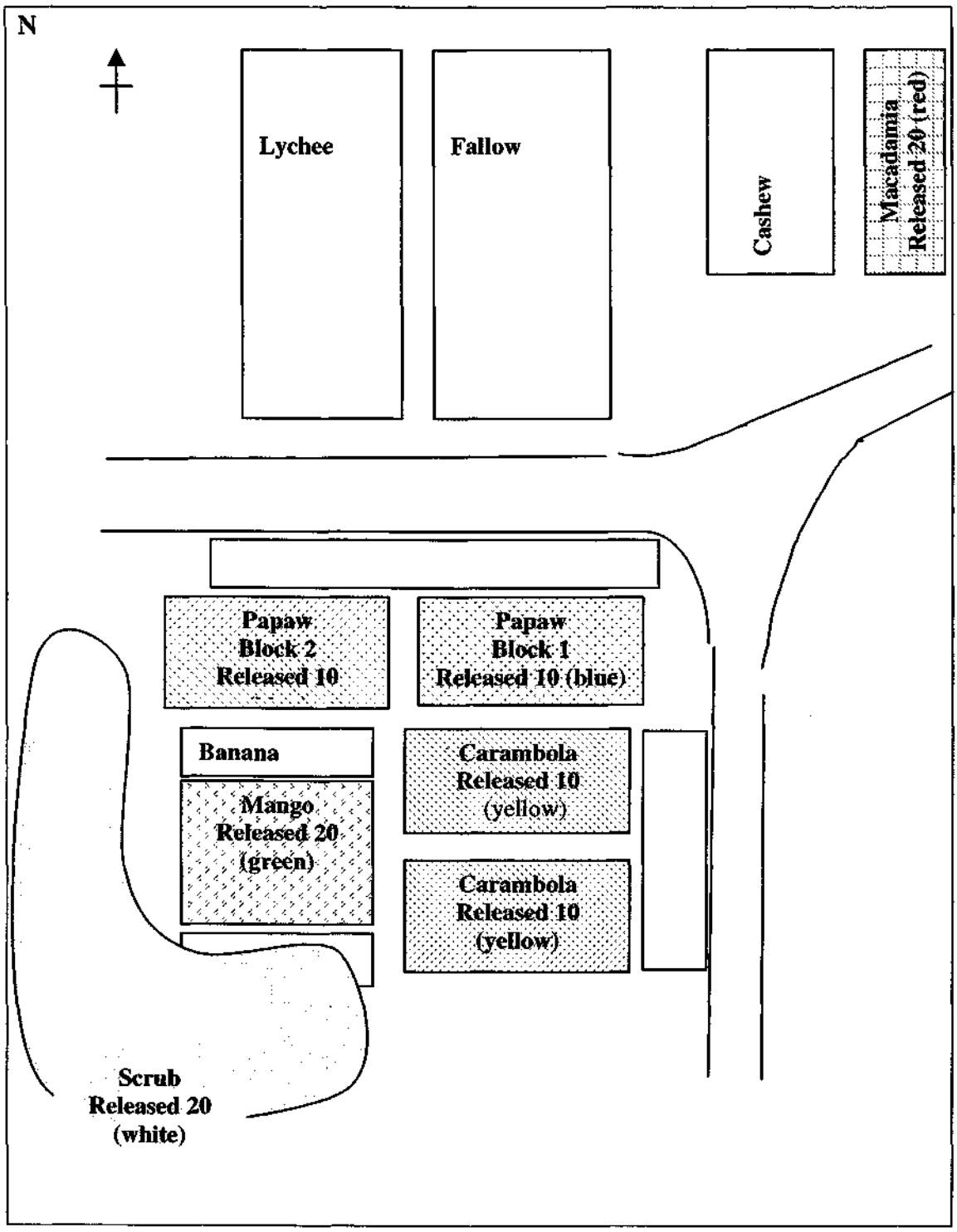


Figure 3. The release points and disc colours of marked bugs at Walkamin Research Station.

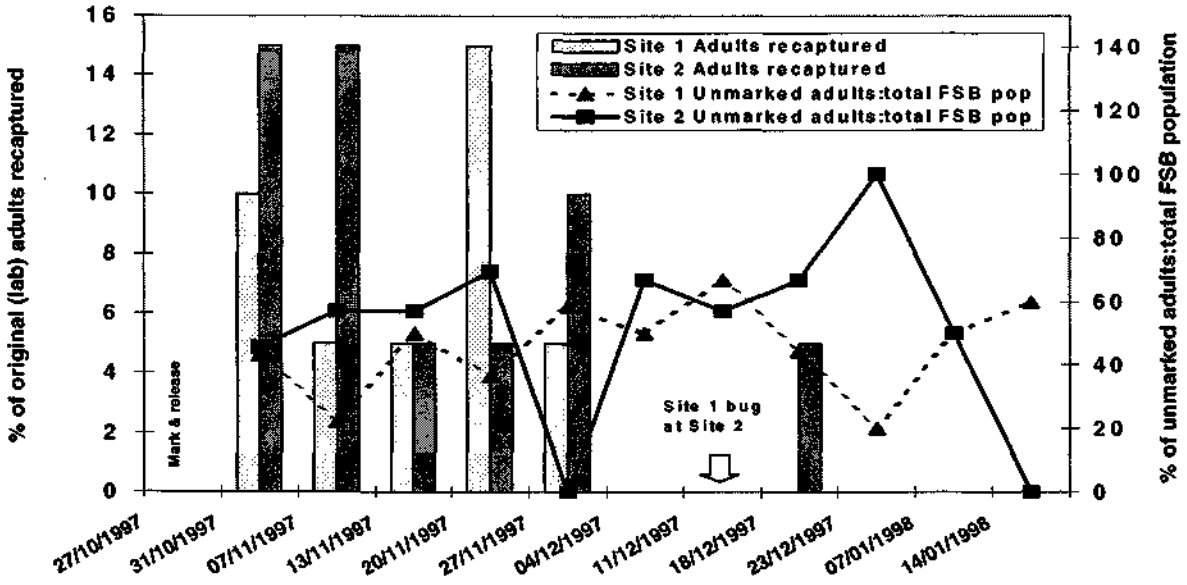


Figure 4. Changes in the rate of recapture of 'lab' FSB and the recruitment rate of new adults in two clumps of mock orange at Mareeba

Papaws – Walkamin

None of the marked bugs released in the macadamias, mangoes, carambolas or eucalypt scrub were subsequently detected in either of the two blocks of papaws. However, there were 11 recaptures in the papaw crop, of bugs that were released in this crop, representing 45% of the total bugs marked with blue discs (Figure 5). Two marked bugs were recaptured twice, one on successive days and the other three weeks after its first recapture. In the latter case the bug had survived for five weeks in the field. The majority of the recaptured bugs were found in the vicinity of the release trees, and only a few had dispersed as far as several rows away.

Throughout the study period the total number of adults marked and unmarked, and nymphs declined at approximately the same rate (Figure 5), despite there being about three times as many nymphs as adults present during the first four weeks of observations. This decline was regarded as seasonal and not related to a change in plant quality and hence attractiveness to the bugs and suitability as a host. This scenario suggests a number of possible causes for the observed population changes: (a) it may indicate that the nymphs were subjected to significant mortality and few survived to maturity (b) as the nymphs matured and became adults, most dispersed from the mock orange bushes on which they developed or (c) while one or both of (a) and (b) were occurring, there was a net emigration of adults from the hosts, even though there was also continuous immigration.

Discussion

The data suggest that adult bugs can be relatively sedentary in host plants that provide ongoing food and shelter. Such plants can become hotspots of bug activity, as continued breeding and immigration can lead to an escalation in the numbers of bugs and in the damage they cause. The extent of immigration appears to depend on the host plant involved and the stage of fruit development where relevant, its situation in

terms of sources of bugs, and the general level of bug breeding at that time. It was surprising that none of the marked bugs released outside the papaw crop were detected within that crop, as it generally would have offered more food than any of the surrounding crops. The released bugs had been fed on papaw plants prior to their use in the experiment to condition them so there was an expectation that they would seek out similar food once in a free choice situation. Within a crop itself, while bugs can occur widely throughout, there are trees in which a greater level of activity is concentrated (Figure 6). This includes both breeding activity and the persistence of adults at the one site. In the papaw experiment the marked bugs were noticeably sedentary, with few moving more than a few metres from the original release point. In the mock orange experiment it is difficult to say whether there was much emigration, but the general impression was that although some did occur a greater proportion of the marked bugs remained *in situ*.

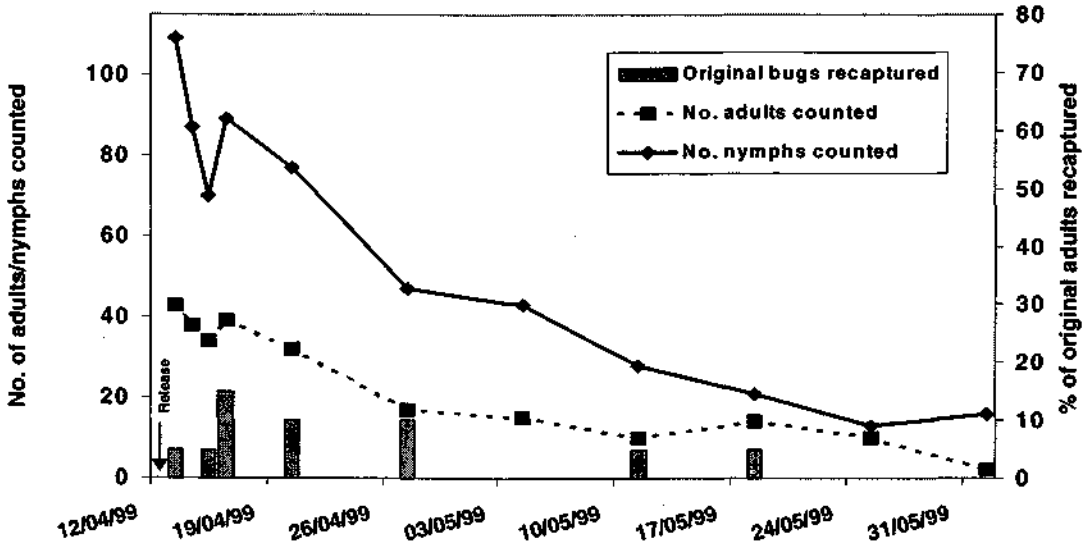


Figure 5. Recaptures of (blue) marked bugs in a papaw crop at Walkamin and changes in the total number of FSB adults and nymphs through the sampling period.

The results of these experiments don't answer the question, "How far will bugs move to find a suitable host?". However, they do help to explain why hotspots develop and how damage levels could be moderated if detection is early enough to circumvent a build-up. From previous studies (Ryan, 1994) and from the results of other work in this report it is known that hotspots can develop along crop edges close to sources of bugs. Such an edge effect did not occur in the papaw experiment at Walkamin (Figure 6) as there was a net loss of adult bugs over time indicating minimal immigration. In such circumstances it should be relatively easy to control bugs chemically. The critical factors relating to the movement of and subsequent damage by fruitspotting bugs appear to be the identification of sources of bugs in areas adjacent to crops, the seasonal activity levels of bugs and crop susceptibility at any particular time. Long distance migration of bugs into crops is only likely to be of minor significance to the overall pest problem.

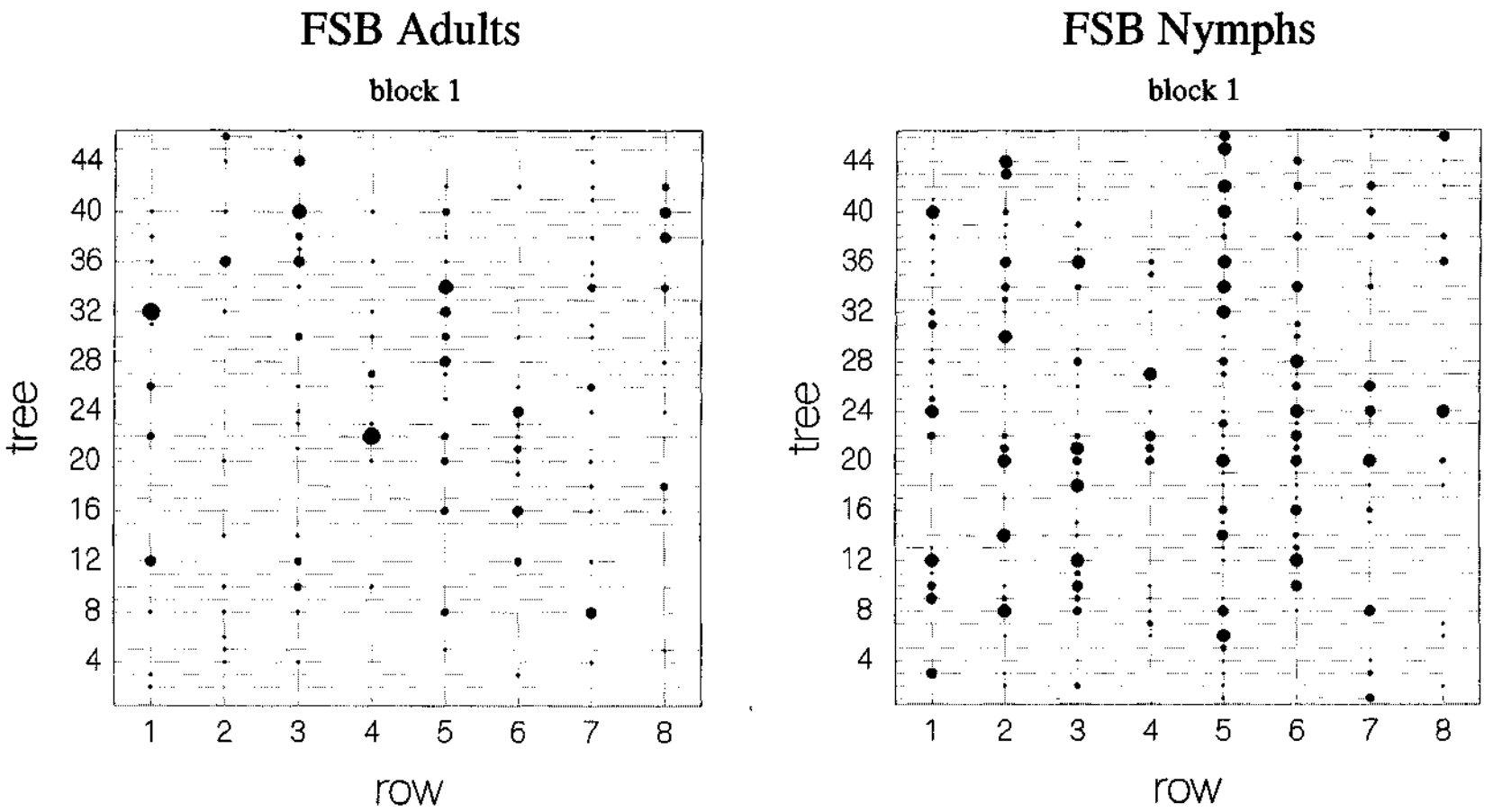


Figure 6. The cumulative pattern of FSB adults and nymphs (marked and unmarked) on individual trees in one block of papaws over the 7 week sampling period at Walkamin Research Station. The larger the dot the greater the number of FSB.

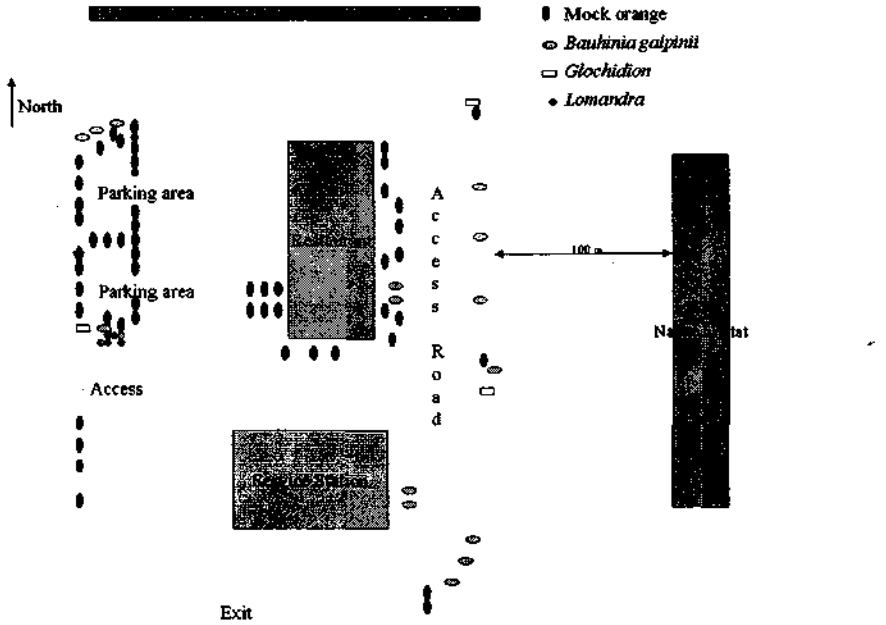
8.2 South Queensland

Studies in mock orange - Forest Glen

Introduction

Two marking techniques were employed at this site – (a) the Tipp-Ex® paint described above and (b) small coloured plastic discs inscribed with individual numbers. These numbers were glued to the pronotum so that bug movement was not restricted. The experiments were carried out in the environs of the BP Service Station at Forest Glen, which is situated just below Buderim on the Sunshine Coast. Figure 7 depicts the general layout of the fruitspotting bug hosts at the site.

Figure 7. Map of Forest Glen 'mark-recapture' site



(a) Experiments using Tipp-Ex® labels

Methods

On 30 September 1997, a mixture of thirty-five adult *A. nitida* and *A. lutescens* collected on five mock orange trees, were marked with different colour combinations of Tipp-Ex® and released into the same trees. The trees were examined carefully twice each week from 6 October 1997 until 28 January 1998 and the number of marked (and the colour of the mark), unmarked adults and all nymphs was recorded for each tree on each date. Observations were made from about 8.30 am when bugs are exposed while feeding or basking, and lasted no longer than one hour.

Results and Discussion

Of the 35 bugs marked and released, 21 'recaptures' were made over the following six weeks. Most sightings were made 14 days after marking – five bugs were recorded on four of the five datum trees. Most of the marked bugs were not seen again and presumably emigrated from these hosts. Because the painted bugs could be distinguished only as originating on a particular tree and not individually, it is impossible to say how many different bugs were re-captured. Although the data does not show it, observations at the time suggested that probably only six of the originally-marked bugs were recaptured, but on several occasions each. What is apparent and supporting the Mareeba data, is that there is continuous migration into and out of favoured hosts by the majority of bugs while a few individuals stayed for longer. This was demonstrated by the increasing dilution and decrease in numbers of the marked population over time (Figures 8 & 9).

Figure 8. Percent marked bugs recaptured

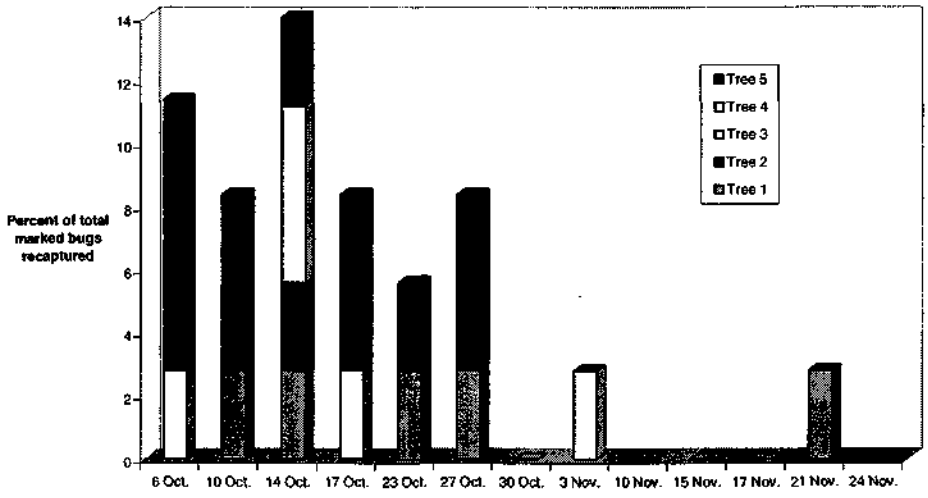
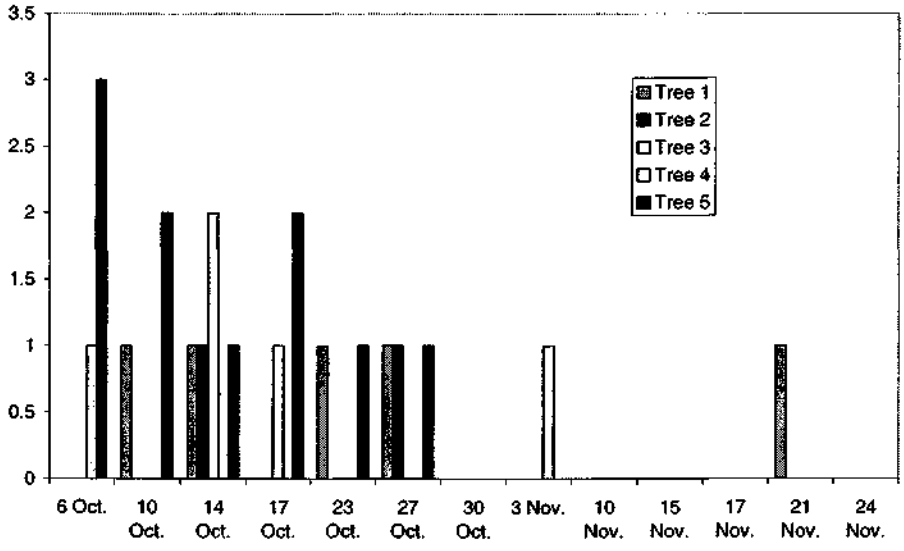


Figure 9: Number of marked bugs per mock orange tree



(b) Experiments with numbered coloured discs

Methods

The introduction of the coloured numbering system allowed individual bugs to be tracked over time and trees. One hundred and thirteen adult bugs representing all of the adults that were seen to be present on 12 December 1998, were captured on the mock orange trees at the Forest Glen site. They were all numbered by gluing a coloured numbered disc to each and re-released into the same mock orange trees. Over the ensuing six weeks all of the known fruitspotting bug hosts growing around the site were inspected twice a week and the presence of both marked and unmarked bugs was recorded.

Results and discussion

During the six week assessment period 61 marked bugs (54%) were observed during twelve assessment sessions. Of these marked bugs ten were observed on two occasions and most of these sightings were made within two weeks of marking and release. One of these double sightings was after three weeks and another after four weeks. 45.9% of all sightings were made within two weeks of release but marked bugs kept appearing so that 49.2% were recorded during weeks three and four. Only 4.9% of the marked bugs were seen after four weeks. During the assessment period, 488 sightings of unmarked bugs were made. Many of these probably were repeat sightings of the same individual bugs, but these data support the conclusions of other studies that many new bugs will have moved in.

Not all observations of marked bugs were made on the mock orange trees. Towards the end of the experimental period, numerous marked bugs migrated to various *Bauhinia galpinii* trees, especially those in full flower and situated at the northern end of the gardens. This coincided with the fruit load on the mock orange trees beginning to diminish and they became less attractive and suitable as a bug host. On the other hand, the *Bauhinia* trees being in full flower were apparently very attractive to the bugs, which fed on the buds and calyx of the open flower. Six marked bugs were recorded on this host, having moved there from the mock orange trees on which they were released. However of the 488 total sightings of unmarked bugs, 341 were on *Bauhinia*. In addition, two other newly-recorded hosts, *Lomandra* and *Glochidion*, came on line at the site when they set fruit, and although these also attracted some bugs away from the mock orange, no marked bugs were found on them.

(c) Longans at Maroochy Research Station

Methods

Sixty-five *A. nitida* adults were caught, marked with coloured numbered discs and released onto the same longan trees in a block of 50 trees, on four occasions in January 1998. A similar study was conducted in 1999.

Results and discussion

In 1998 in this orchard situation only three marked bugs were seen again with only two of these being within the study orchard. These were either in the same tree into which they had been released or in a tree nearby. The third was recaptured six days after release in a longan tree in the Research Station Cultivar Collection Block, some 200m to the west. Since the total capture of wild bugs for the whole block on each occasion was a consistent 12-17 bugs per day, the conclusion was that there is a constant movement of bugs into and out of the orchard with previous visitors, amongst them the marked bugs that were released, not necessarily returning.

Of 72 marked *A. nitida* adults released over a period of four weeks in 1999, there were 24 sightings over a six week period that included the release period. Of these, 13 sightings (54.2%) were within one week of release while 10 marked bugs (41.6%) were seen two to three weeks after release. One individual was first seen 21 days after release and again after 32 days. A total of 199 new wild bugs was collected from the longan trees during this time, again suggesting that continuous immigration was taking place. The immediate disappearance of over half of the marked bugs after release and the gradual disappearance of the rest as time elapsed, combined with the large number of new arrivals, further supports the results of the previous studies. Contrary to our former thinking and the suggestion from the Mareeba experiment that infestations of bugs gradually develop through recruitment of migrants over time, with new arrivals remaining within a relatively restricted area of an orchard or in certain trees to form hotspots, the data obtained in these experiments suggest that bugs come and go. They do not necessarily move much between trees within the orchard, at least for extended periods. This helps to explain how hotspots are formed in commercial orchards (see section on 'Hotspots').

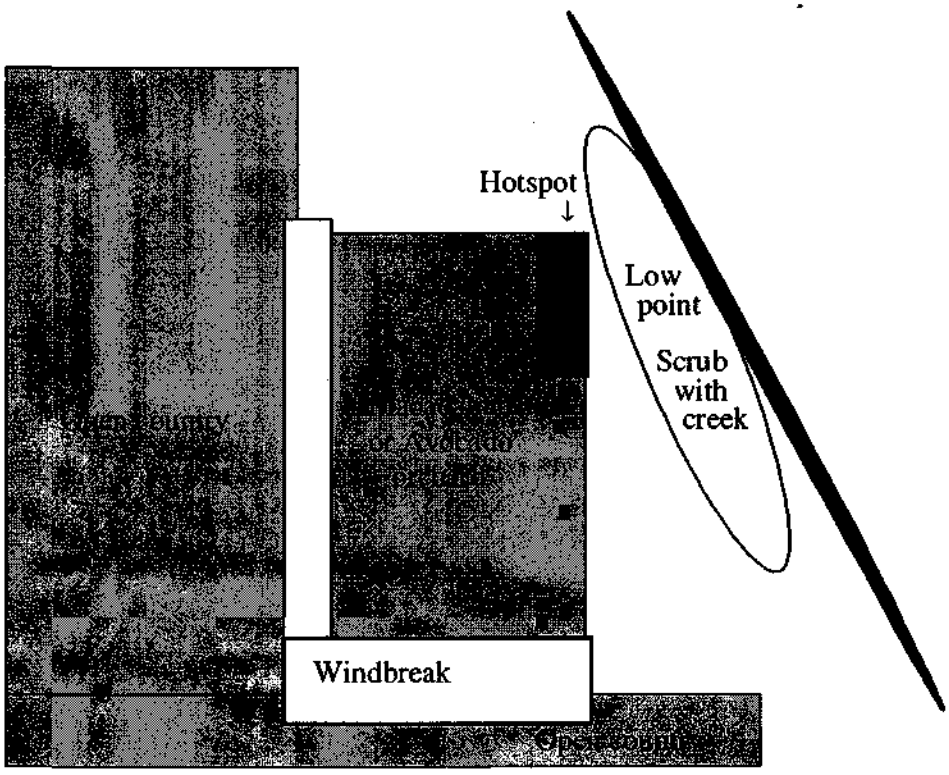
9. High risk orchard types and potential hotspots

9.1 Grower survey

Two-hundred and seven responses were received to the survey sent to growers just prior to the commencement of the project in 1997. On the subject of 'hotspots' and edge effects, 56%, 62% and 64% of avocado, macadamia and custard apple growers respectively recognised 'hotspots' while 53%, 26% and 50 % respectively identified an edge effect with respect to fruitspotting bugs in their orchards. When it came to identifying characteristics of orchards exhibiting these phenomena, the most significant feature cited was the presence of adjacent vegetation. Rainforest was most frequently specified as the nearest habitat type, but camphor laurel, especially in northern NSW and lantana both featured as suspected bug breeding habitats. Neither of the latter two plant species has been recorded as fruitspotting bug hosts! Geographical features such as high, low or sheltered areas were blamed about equally by those growers who offered an opinion as to whether such features affected the distribution of bug damage in an orchard.

Through a series of on-site and personal interviews, these results were further refined. By combining all results, a typical fruitspotting bug 'risk' situation has been constructed (Figure10) so that potential hotspots can be pin-pointed in individual orchards to assist in bug monitoring, and the application of what is envisaged to be a future 'targeted spray' approach to fruitspotting bug management. Often, edge effects became hotspots and *vice versa.*

Figure 10. Schematic 'hotspot' situation for fruitspotting bug

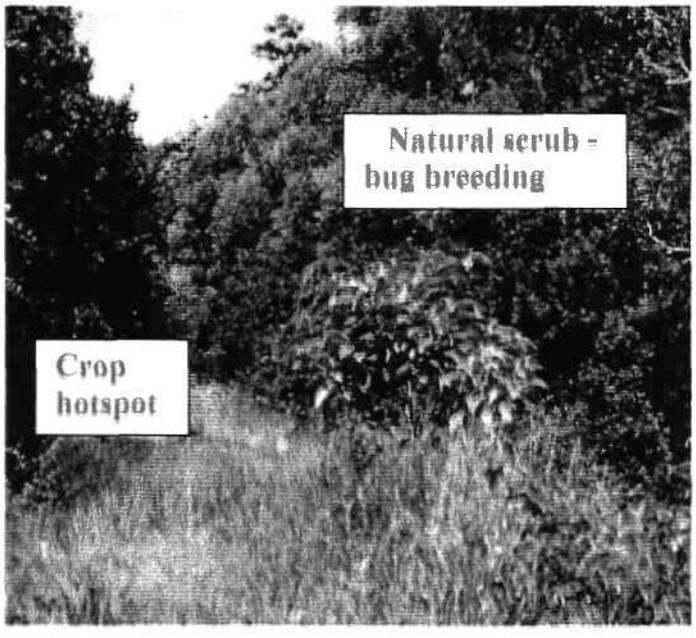


9.2 Field sampling

Areas of avocado orchards where bug damage was high were identified through on-farm surveys of growers as described above (Figure 10) and then by sampling trees along transects in a sprayed and an unsprayed orchard. For each transect, fruit on every second tree in alternate rows was sampled and assessed for fruitspotting bug damage.

The orchard transects confirmed the existence of hotspots. In the unsprayed orchard the hotspot was confined largely to the first three rows adjacent to native vegetation and might be considered an edge effect rather than a hotspot (Plate 6, Figure 11). Damage levels decreased from 65% in the outside row to 30% and 13% in the next two rows. Damage further from the edge decreased to 2-3%. In the sprayed orchard, damage also decreased as the distance from the orchard boundary increased, but the level of damage was high throughout the block and ranged from 75% in the outside row through 55% in the middle transect and 25% in the sixth row (Adkins, 1998) (Figure 11). Damage was not recorded in rows beyond the sixth, but visual assessments indicated that as distance from the edge increased, damage levels decreased, but were still moderate. The amount of fruitspotting bug damage in each of the orchard hotspots was high and this incidence, while it is hoped that normal control measures would prevent it, should not go unnoticed by the grower. Such hotspot developments should be used positively by growers, not only for monitoring purposes but also for control where more frequent sprays might prevent bugs and the concomitant damage from spreading throughout the orchard.

Plate 6: Typical orchard hotspot situation with outside rows immediately adjacent to natural scrub



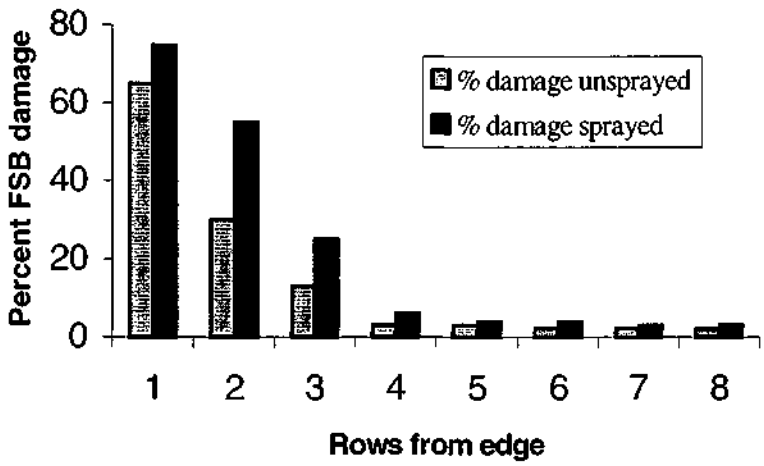


Figure 11: Edge effect of fruitspotting bug in avocados measured by percent damage to fruit on transects through the orchard

9.3 Observations in a commercial custard apple orchard

For two summer seasons in 1998/99 and 1999/00, Bill and Jane Thompson, custard apple growers at Glasshouse on the Sunshine Coast, kept a daily tally of *Amblypelta* spp. seen and caught on individual trees in their orchard. The orchard was mapped and each tree was given a number. The orchard, consisting mostly of the cv. Pinks Mammoth planted in two separate blocks, was virtually unsprayed. Bug control was through daily capture of bugs observed on the flowers and fruit. The records so generated have been used to attempt to fathom if there was any pattern to fruitspotting bug infestations on an orchard scale.

The records confirmed that there were two definite areas of the orchard, both in the same block, that could be regarded as hotspots. Both of these were known to the growers through many years of observation and study. One area consisted of a couple of trees of cv. African Pride, which is apparently more attractive to the bugs than is Pink's Mammoth. The other centred around custard apple trees close to other bug hosts such as guava and native scrub. In the other block situated about 100m away and across a gully containing several known fruitspotting bug hosts, obvious general hotspots were not evident. However in the 1999-2000 season one tree in particular was an exceptionally 'hot tree', with 34 adults and 8 nymphs being caught on it. As might be expected, this tree was adjacent to the gully scrub but the number of bugs attracted to it was unusual, especially as none had been seen on it in the previous season. An interesting aspect was that no bugs were seen on this tree after 26 December 1999, and yet significant numbers of bugs were still being caught in the orchard as late as mid-April 2000. What made this tree so attractive to immigrating bugs and why did that attraction apparently switch off late in December? According to the growers there was nothing unusual about the tree. Observations such as this offer tantalising suggestions as to the factors that might influence bug behaviour. The theory that plant volatiles alert bugs to the possibility of finding food and then attract them, gains support. Overall bug populations in the orchard in 1999/00 were significantly higher (210 adults, 194 nymphs) than in 1998/99 (158 adults, 159 nymphs) (Table 4).

The records of catches on various hosts in the early part of the season reflect the bugs' over-wintering behaviour and re-activation in spring. For several seasons now we have been aware that citrus is a favourite over-wintering host. As other potential summer fruiting hosts start to flower, the typical host-sequencing phenomenon commences with adult bugs feeding opportunistically on each type of fruit as it sets, and laying eggs.

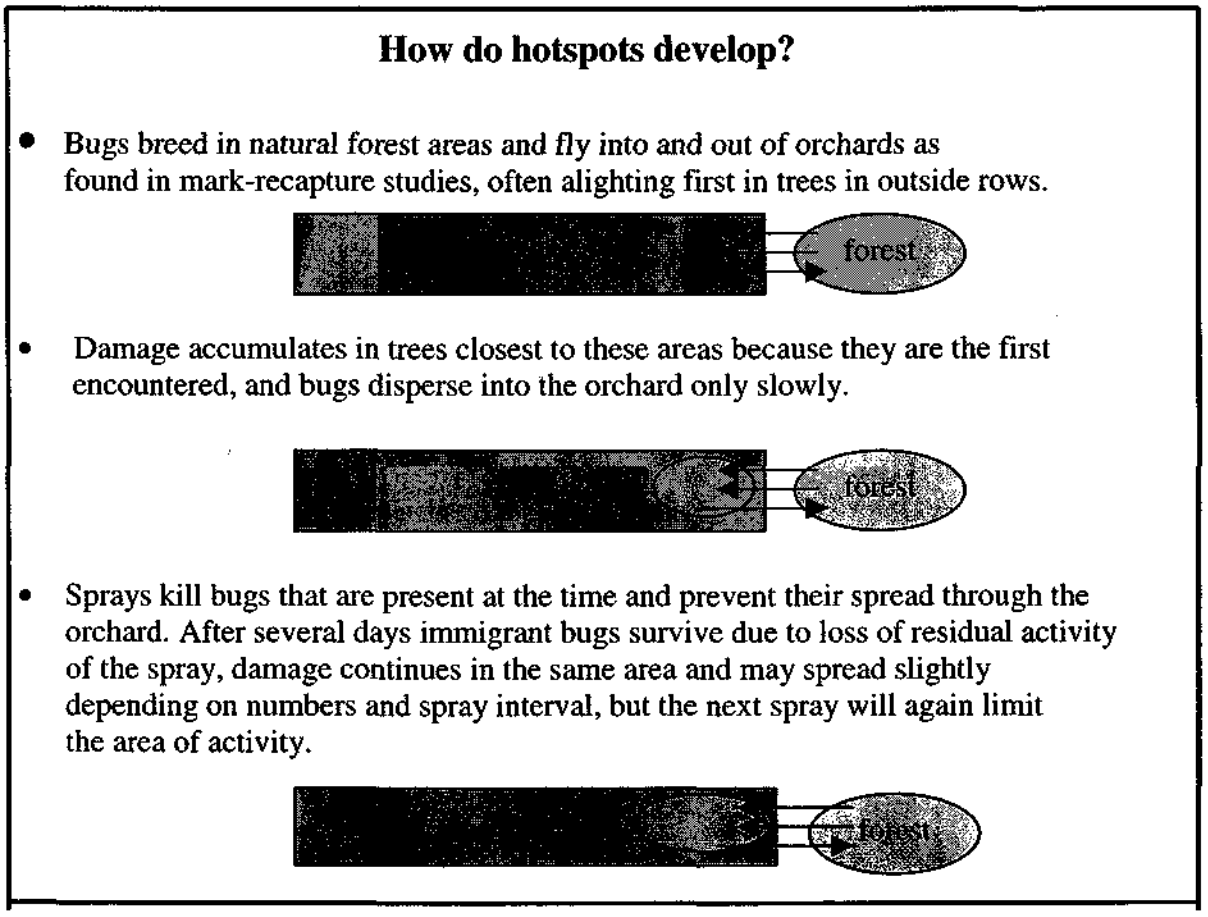
Table 4: Weekly catches of *Amblypelta* spp. on custard apples and other hosts at glasshouse In 1998/99 and 1999/00 (data supplied by Bill and Jane Thompson, Dimboola)

	1998-99					1999-00			
Week	Adults	Nymphs	Total	Main host	Week	Adults	Nymphs	Total	Main host
15-Sep-98	21	0	21	Citrus					
21-Sep-98	2	0	2	Persimmon					
28-Sep-98	0	0	0	"					
5-Oct-98	2	0	2	"					
12-Oct-98	1	0	1	Avocado					
19-Oct-98	15	1	16	"	18-Oct-99	4	4	8	Persimmon
26-Oct-98	7	3	10	"	25-Oct-99	3	1	4	"
2-Nov-98	2	0	2	Cust. apple	2-Nov-99	6	3	9	"
9-Nov-98	1	9	10	"	9-Nov-99	0	1	1	Avocado
16-Nov-98	2	5	7	"	16-Nov-99	3	6	9	Cust. apple
23-Nov-98	3	9	12	"	23-Nov-99	17	30	47	"
30-Nov-98	6	14	20	"	30-Nov-99	22	22	44	"
7-Dec-98	0	0	0	"	7-Dec-99	41	43	84	"
14-Dec-98	6	8	14	"	14-Dec-99	15	40	55	"
21-Dec-98	8	5	13	"	21-Dec-99	14	19	33	"
28-Dec-98	4	4	8	"	28-Dec-99	15	19	34	"
4-Jan-99	5	3	8	"	4-Jan-00	14	19	33	"
11-Jan-99	12	5	17	"	11-Jan-00	8	7	15	"
18-Jan-99	3	9	12	"	18-Jan-00	2	2	4	"
25-Jan-99	5	8	13	"	25-Jan-00	6	15	21	"
1-Feb-99	4	5	9	"	1-Feb-00	3	8	11	"
8-Feb-99	7	8	15	"	8-Feb-00	2	6	8	"
15-Feb-99	8	6	14	"	15-Feb-00	1	10	11	"
22-Feb-99	14	26	40	"	22-Feb-00	3	3	6	"
1-Mar-99	2	12	14	"	29-Feb-00	8	5	13	"
8-Mar-99	2	6	8	"	7-Mar-00	7	6	13	"
15-Mar-99	3	2	5	"	14-Mar-00	3	1	4	"
22-Mar-99	3	8	11	"	21-Mar-00	4	6	10	"
29-Apr-99	4	1	5	"	28-Mar-00	2	5	7	"
5-Apr-99	1	1	2	"	4-Apr-00	2	8	10	"
12-Apr-99	3	0	3	"	11-Apr-00	1	4	5	"
19-Apr-99	0	0	0		18-Apr-00	2	0	2	"
26-Apr-99	0	3	3	"	25-Apr-00	2	1	3	"
Total	158	159	317		Total	210	194	404	

9.4 How do hotspots develop, and how can the phenomenon be used to advantage?

Various components of the total project study can be combined to formulate a theory as to how fruitspotting bug hotspots develop in commercial orchards. To do this, the responses of growers, the results from the mark-recapture studies that looked at bug movement, and the edge effect studies in which transects were used to plot the area of major bug activity in orchards were considered.

Figure 12: Hotspot theory 'A'



Obviously the pattern of damage that results will never be as clear-cut as that depicted in the accompanying Figures 12 & 13. These are for illustration only. There will always be bugs that move around more than average and so can attack fruit in any part of the orchard. Also, adjacent forest may not be the only source of immigrant bugs so that some may enter the orchard at other points.

Because of this behavioural characteristic that is more or less predictable, a management strategy for fruitspotting bugs that makes use of hotspots for both monitoring and control should be possible. The first requirement at the orchard level is for each grower to identify existing hotspots and to map them. This can be done during the season by regular monitoring of damage as it occurs or at harvest when hot trees or areas in the orchard will become apparent by the amount of

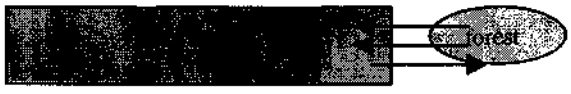
bug damage that shows up. Even though for the thin-skinned cultivars that are very susceptible to anthracnose infection, the full extent of the damage may not be evident at that time, there should still be sufficient damaged fruit remaining on the trees to indicate the existence of a hotspot. Studies described elsewhere in this report (see Fruit Phenology section) found that a significant proportion of damaged Fuerte fruit fell, especially during the natural fruit drop period. Many fruit also fell later as the wet season and heat promoted anthracnose infection of fruitspotting bug lesions.

By the time harvest commences much of this damaged, fallen fruit will have rotted away and unless a grower has inspected the orchard frequently in the lead-up to harvest, he may be oblivious to this unseen damage. To adequately manage fruitspotting bugs, every grower or orchard manager needs to record the history of attack over several seasons. Knowing where the major hotspots are will help in monitoring and also the targeted spraying of these areas so that an effective IPM system can be implemented.

Figure 13: Hotspot theory 'B'

How do hotspots develop?

- Bugs breed in natural forest areas and fly into and out of orchards as found in mark-recapture studies, often alighting first in trees in outside rows.



- Damage accumulates in trees closest to these areas because they are the first encountered, and bugs disperse into the orchard only slowly.

- Damaged fruit liberates volatiles that attract more bugs into those trees and the damage intensifies. These volatiles may include 'phytodistress signals' that may also attract natural enemies of the bugs.

- Sprays again prevent the spread of bugs and intensify the effect of the attraction and resultant damage.

10. Laboratory and field trials of alternative chemicals to endosulfan for fruitspotting bug control

Introduction

Fruitspotting bugs, *Amblypelta* spp. (Hemiptera: Coreidae), are significant pests of horticultural tree crops such as macadamias (Ironside, 1981), avocados (Swaine *et al.*, 1985), lychees and custard apples (Waite *et al.*, 1993) in Queensland and northern NSW. Both adults and nymphs feed by piercing and sucking on developing fruit causing premature fruit fall or a serious down grade of quality. An individual adult per tree has the potential to cause significant damage, sufficient to justify chemical intervention (Rice *et al.*, 1997).

Endosulfan is the preferred pesticide option for most growers and is perceived as being soft on beneficials. In macadamia it is useful early in the season to control fruitspotting bug and macadamia nutborer, *Cryptophlebia ombrodelta* (Lower), when it becomes active. It is the only chemical registered for bug control in avocados.

In 1998, endosulfan was reviewed by the National Registration Authority (NRA) as part of its ongoing review process of agricultural chemicals currently registered for use in Australia. Endosulfan survived the review, but with a number of restrictions placed on its use and how it could be used. Changes in labelling imposed by the NRA due to improved toxicological and environmental data, limit the use of this product in certain crops and its continued use at the urban/rural interface will be contentious. Further, the fortnightly spray regime of endosulfan sprays often used by the avocado industry does not conform to best practice principles. The need for such a program suggests that the efficacy of the pesticide is questionable or the application technology used in tree crops may be inappropriate.

Industries in which endosulfan is used and for which no maximum residue limit had been set, were given a deadline to carry out the necessary procedures to obtain residue data to allow MRLs to be set, or the chemical could no longer be used. It appears that despite the current reprieve, regulatory eyes will be continuously fixed on endosulfan to ensure it is used correctly. Public attention has been focussed on endosulfan through well-publicised problems caused by the cotton industry in relation to grazing land and also as a result of some fish kills on the Sunshine Coast. The next major transgression by any industry may well result in its loss to all, including the horticultural industries that rely on it for fruitspotting bug control.

Evaluation of pesticides for the control of *Amblypelta* spp. is difficult in the field. This is due to the sometimes sporadic occurrence and clumped distribution of the pest in orchards and the low threshold for economic damage. Further, there is distrust of the efficacy of some of the currently registered pesticides by some producers. This may be more a reflection of the application technology used rather than the efficacy of the pesticide itself.

The apparent enhanced control achieved by using endosulfan at night as opposed to daytime spraying at least in the macadamia industry, suggests better control is achieved possibly because of reduced rates of volatilisation associated with lower ambient temperatures and higher relative humidity. Also, there may be an insect behavioural response at night eg. less flight, which results

in the bugs remaining in contact with the insecticide for longer. Regardless of the reasons for the perceived enhanced control at night, if they are found to have a basis in fact these anecdotal findings may be useful for application to other crop situations. Further, confusion with fruit fly damage, *Phomopsis* infection and fruitspotting bug damage may still be occurring in some industries. Such confusion can only be resolved by individual producers undertaking intensive crop loss assessments in each of the crops affected to identify the causal agents.

Because of the tenuous nature of the current registration for endosulfan, it was considered necessary to explore the options for alternative chemical controls for fruitspotting bugs. The nature of the problem is that mobile adult bugs migrate into orchards and are the prime causal agents of damage to fruit. There is no current option but to apply chemical sprays to kill these bugs to prevent damage. Such damage might extend to 90% of the crop if no control was applied. Suitable chemicals will ideally have good knockdown characteristics as well as reasonable residual activity. Such chemicals do exist, but the very attributes that make them good bug killers are those that cause other problems within the orchards, such as flares of mites and scale insect pests caused by disruption of their parasites and predators.

In planning for the research to investigate alternative chemical controls, these matters were thoroughly considered. While we recognised the shortcomings of some of the potential candidates, we felt that if in the end one of the more broad-spectrum chemicals had to be used, then that use could probably be tailored and integrated in such a way as to mitigate any detrimental effects. This task would be made simpler if endosulfan remained available so that the chemicals could be alternated. The addition of an alternative chemical correctly managed, could also serve to enhance the effects of endosulfan and by reducing its frequency of use may also assist in its longer availability to the horticultural industries.

In avocados additional data were required for the purposes of registration of beta-cyfluthrin in that crop, since Bayer Australia Limited already was in possession of some data, but needed further information to support an application for registration. It was deemed important to obtain an alternative registration quickly, since despite the positive result of the review of endosulfan use conducted by The National Registration Authority, it was considered that the continued availability of endosulfan was by no means guaranteed.

In addition to the efficacy trials in these crops, experiments were conducted to determine the residual activity of the chemicals to fruitspotting bugs through cage experiments on papaw, and also to representative parasitoid and predator species using a purpose-built apparatus containing a series of replicated Munger Cells. The acquisition of these data was necessary to provide an indication as to how the chosen chemicals affect natural enemies and for how long, and thus how suitable they might be for incorporation into workable IPM systems.

10.1.1 Laboratory bioassays and associated field trials

Objectives

The aim of this sub-project was established at the Fruitspotting Bug Planning Meeting held in Brisbane on 29 October 1996, involving representatives from the macadamia, avocado and

custard apple industries, NSW Agriculture, Queensland DPI, Sunshine Coast Subtropical Fruits Association and HRDC. Both the chemicals (technical grade) and the methodology employed (topical application) were agreed to at that meeting. The specific aim of this component of the work was to evaluate in the laboratory, currently registered pesticides for fruitspotting bug control, and to undertake preliminary screening of possible alternative chemicals particularly fluvalinate, as a replacement for endosulfan. We then selected commercial products incorporating the relevant active compounds for testing in the field using caged insects on macadamia racemes.

Methods

Insects: All insects used for both laboratory and field testing purposes were taken from the fruitspotting bug culture maintained at TFRS. The laboratory strain was established using wild bugs collected from the field in the Alstonville area. The bugs were cultured on pesticide-free green beans, *Murraya paniculata*, known as mock orange or orange jessamine, and macadamia, longan and avocado when these crops were in season. The vigour of the culture was maintained by varying the diet and through the regular addition of field collected bugs. For testing purposes only hardened adults older than one week, were used.

For quarantine reasons only *Amblypelta nitida* was used in field tests at TFRS as the banana spotting bug, *Amblypelta lutescens lutescens* (Distant) has not been recorded in northern NSW, and it would have been necessary to import a culture from Nambour. Both species are significant pests in horticultural crops in Queensland.

Chemicals: Technical grade samples of bifenthrin, tau-fluvalinate, endosulfan, chlorpyrifos, beta-cyfluthrin and trichlorfon were provided by N. Forrester (Cotton CRC, Narrabri). R. Bull (Rhone-Poulenc Rural Aust. Pty. Ltd.) provided the fipronil and Neemoil Australia provided the azadirachtin. With the exception of the azadirachtin, the pesticides used were selected on the basis of their existing registrations, known toxicity and environmental acceptability. The active component, trade name, chemical group and purity of each test sample are shown in Table 5.

Laboratory screening: For each chemical a 0.1% stock solution in acetone was prepared, except for azadirachtin for which isopropanol was used as the solvent. Serial dilutions in the range 10^{-2} to 10^{-7} with acetone, and isopropanol in the case of azadirachtin, were made and the discriminating dose range corresponding to zero and 100% kill for each pesticide approximated. Initial sample sizes were small (5 insects/concentration) and an indicative LD50 and LD95 was estimated using Probit Analysis (Gillespie, 1995), corrected for control mortality (Abbott, 1925). Background mortality for each chemical was assessed using the solvent, acetone or isopropanol as the control.

Table 5. Active component, trade name, chemical group and chemical purity of test used in topical application assessment against *Amblypelta nitida*.

Active component	Trade name	Chemical group	Chemical purity
Bifenthrin	Talstar	Pyrethroid	90.4
Tau-fluvalinate	Mavrik	Pyrethroid	91.1
Endosulfan	Endosulfan	Organochlorine	98.1
Chlorpyrifos	Lorsban	Organophosphate	>94.9
Beta-cyfluthrin	Bulldock	Pyrethroid	97.0
Trichlorfon	Lepidex	Organophosphate	99.0
Fipronil	Regent	Phenylpyrazole	91.4
Azadirachtin	Neem extract	Triterpenoid	45.0

Fruitspotting bugs were immobilised by placing groups of five individuals in a glass vial in a freezer at -18°C for 3 minutes. The insects were then arranged on a filter paper in 500ml ventilated plastic containers, with their dorsal surface facing upwards. A test dose of a single 1µl droplet was applied to the thorax of each insect using a Hamilton micro-applicator. After the fruitspotting bugs were treated, fresh beans were added to each container. Containers were closed and maintained at approximately 25^0C (14L:10D). Mortality after 1, 2, 3 and 7 days was scored, depending on the chemical tested. All stock solutions were stored at 4°C after preparation to prevent evaporation.

To improve the accuracy of the initial parameter estimates, additional dilutions were made and tested against 15-20 insects with three or four replicates of five insects per concentration ie.120-140 insects per chemical, and the results were again subjected to a Probit Analysis. Bugs were considered dead if no movement was discernible after tactile stimulation with a fine brush.

After seven days the surviving female fruitspotting bugs exposed to azadirachtin were fed new beans and monitored for subsequent effects on oviposition.

Field screening: Based on the laboratory results, commercial products containing the most promising compounds including industry standards, were field tested on macadamia. All treatments were confined to an individual tree for a particular trial. The trees, either cv. Renown or cv. 783 were 14 years old and located in the Accession Block at TFRS. Each tree was divided into quadrats containing three replicate racemes per treatment to minimise the effect of spray drift. On each raceme all nuts had reached full size with hard shells. Chemicals were applied to the point of run-off with a hand spray to individual tagged racemes. Field cages were attached to individual racemes after the spray had dried (see Campbell *et al.*, 1999 for cage details), and two male and two female fruitspotting bugs were added to each cage. Mortality was assessed daily for seven days after caging of the bugs using the criteria outlined above. Depending on the trial the effect of one and three day-old residues was examined to simulated control of invading bugs from outside the orchard. Trial size was limited by the availability of suitable numbers of bugs and the need to maintain a viable culture for laboratory screening purposes.

Trial 1

Trial 1 commenced on 15 February 1999, when growers confirmed that relatively high numbers of fruitspotting bugs had appeared in the field. Sandoz Aquaflow Mavrik® (240gm/L tau-fluvalinate) was unavailable at short notice. Yates Mavrik® for garden use containing 7.5g/L tau-fluvalinate (1/32 the strength of Sandoz Aquaflow) was substituted and applied at three rates (Table 6). Endosulfan at 1.5 ml/L (the currently registered rate) was used as the comparison, with water used as a control. A sticker, Sprayfast®, was added to all chemicals at the rate of 0.3ml/L and treatments were confined to a tree of the cv. Renown. Test insects were caged one day post spraying.

Trial 2

In Trial 2 commencing 5 March 1999, Sandoz Aquaflow Mavrik® (240gm/L tau-fluvalinate) replaced the Yates Mavrik®. Bulldock® and Endosulfan® at 0.5 and 1.5ml/L respectively, the current registered rates, were included as industry standards along with a water control (Table 6). Treatments were confined to the cv. 783 and Sprayfast® was added as above. In this instance bugs were not caged on the fruit until three days post spraying.

Table 6. Pesticide formulations mixed to give the accepted field rates of 0.2ml/L Mavrik Aquaflow and Endosulfan 1.5ml/L (375 g/L Endosulfan). Note different dilutions of Mavrik depending on the formulation used.

Trial	Treatment	Concentration used (ml/L)	Rate (g ai/L)
1	Control	0	0
	Yates/4 (Mavrik)	1.6	0.012
	Yates/2 ..	3.2	0.024
	Yates ..	6.4	0.048
	Endosulfan	1.5	0.562
2	Control	0	0
	Sandoz/4 (Mavrik)	0.05	0.012
	Sandoz/2 ..	0.1	0.024
	Sandoz ..	0.2	0.048
	Endosulfan	1.5	0.562
	Bulldock	0.5	0.0125

Results

Laboratory assay

A total of 2022 fruitspotting bugs adults was tested in 19 separate assays during 1997/98 using the topical application technique. Although mortality was recorded at 1, 2, 3 and 7 days, only the Day 3 scores were analysed using Probit Analysis because the increasing control mortality (20-50%) made the analysis unreliable. The discrepancies in control mortality (>19 % at day 3) for azadirachtin (the active component of Neem) and chlorpyrifos cannot be explained as all insects were from the same source and treated and handled in the same manner (Table 7). Because of a shortage of insects, not all pesticides were tested simultaneously once the discriminating doses for zero and 100% kills were established.

Disregarding azadirachtin, the least efficacious chemical was the organophosphate chlorpyrifos (LD50 of 0.0779 g ai L^{-1}). Of the pyrethroids, the newer chemicals bifenthrin and beta-cyfluthrin (LD50 of 0.000571 and 0.000396 g ai L^{-1} respectively) were clearly an order of magnitude better than the older tau-fluvalinate (LD50 of 0.00122 g ai L^{-1}). The currently registered products, endosulfan, trichlorfon and chlorpyrifos, were inferior to the newer products screened. Fipronil was more efficacious than tau-fluvalinate but less so than bifenthrin or beta-cyfluthrin.

Table 7. Dose–response data for *Amblypelta nitida* tested against a number of registered and candidate pesticides.

Compound	Control Mortality (%)	Day 3 LD50 (g ai L^{-1})	(g ai L^{-1})	Upper FID limit	Lower FID limit	Slope	Chi-squared (d.f.)
Azadirachtin**	10-33	N/A*					
Beta-cyfluthrin	7.7	0.000396	0.00377	0.00944	0.00151	1.67	5.7 (12)
Tau–fluvalinate**	10	0.00122	0.00721	0.0269	0.00193	2.13	31.1 (13)
Endosulfan	6.7	0.00409	0.243	2.62	0.0225	0.92	19.5 (6)
Chlorpyrifos	40	0.0779	0.272	0.424	0.174	3.02	556 (7)
Bifenthrin**	6.7	0.000571	0.0217	0.0865	0.00543	1.04	39.4 (10)
Fipronil**	6.7	0.000965	0.0172	0.128	0.00230	1.31	4.29 (6)
Trichlorfon	0	0.00797	0.995	14.1	0.0703	0.78	35.7 (13)

* no effective dose was reached for Azadarachtin despite using 10 fold steps up to 0.1 g/L. Probit analysis was inappropriate for the dose range tested.
**Pesticides not registered for use in macadamia.

Observations indicated that sex was an important factor in determining the susceptibility of an insect to a pesticide. Sorting the data by sex and re-analysis clearly indicated that a higher dose was required to kill females than males (Table 8). Females had a consistently greater body weight and were some 40% heavier than males The fresh body weight of female and male fruitspotting bugs was 0.0721 gm (±0.0.0044) and 0.0515 gm (±0.0.0013) respectively (n = 10). More than ten-fold increases in pesticide concentration of beta-cyfluthrin and chlorpyrifos were required to kill females as opposed to males, a ratio greater than that for their body weights. The difference in concentration required to kill females was not consistent across all pesticides within a chemical group and is not entirely due to differences in body weight alone. An insect's ability to detoxify a substance is related to its metabolic rate, which is directly proportional to body weight (Schmidt-Neilsen, 1972).

With azadirachtin there was no evidence of a dose response using isopropanol as the solvent. However increased activity was detected using acetone (Table 9). A significant lethal dose was not achieved and based on information supplied by Neemoil Australia, the cost of concentrations above 0.1gm/L is likely to be prohibitive and such doses would also cause flower burn. Exposure of females to azadirachtin had no conclusive effect on subsequent oviposition rates, regardless of the dose.

Table 8. Dose-response by sex for *Amblypelta nitida* tested against a number of registered and trial pesticides.

Compound	Ranking*	Sex	LC50 (g ai L^{-1})	(g ai L^{-1})	Slope	Chi-squared (d.f.)
Fipronil**	1	female	0.000495	0.00284	2.16	3.42 (6)
		male	0.000372	0.00252	1.97	3.44 (6)
Bifenthrin**	2	female	0.00186	0.00568	3.34	50.4 (10)
		male	0.000261	0.109	0.63	14 (10)
Tau - fluvalinate**	3	female	0.000706	0.0133	1.29	3.90 (5)
		male	0.000432	0.00231	2.25	1.49 (5)
Beta -cyfluthrin	4	female	0.00189	0.449	0.69	5.57 (6)
		male	0.000156	0.0233	0.75	5.69 (6)
Trichlorfon	5	female	0.0298	1.44	0.97	86.9 (13)
		male	0.00631	0.0279	2.54	25.3 (13)
Endosulfan	6	female	0.00389	128	0.36	3.98 (6)
		male	0.00109	0.0261	1.19	10.3 (6)
Chlorpyrifos	7	female	0.234	8466	0.36	10.27 (7)
		male	0.017	0.0221	14.24	348 (7)

** Ranking of efficacy based on LD95 for females.
* Pesticides not registered for use in macadamia.

Table 9. Impact of azadirachtin on *Amblypelta nitida* mortality and subsequent female oviposition rates using isopropanol (ISOP) and acetone (Acet.) solvents to suspend the dose.

Rate gm/L	ISOP. 7day % mortality	ISOP. 7day egg/fem.	Acet. 7 day % mortality	Acet. 7day egg/fem.	Acet. 14day egg/fem.	Acet. 21day egg/fem.	Acet. 28day egg/fem.
Control	33.0	1.6	10.0	0.5	0.5	1.5	6
0.0001	6.7	0.1	30.0	0	0	0	0
0.001	26.7	0.7	13.3	0	0	1.5	1
0.01	20.0	0	46.7	1.7	1.5	1.0	3
0.1	13.3	0	53.3	0.6	0.5	0.5	6

Field assays

Preliminary field mortality data after exposure to residues 1-day post spraying are presented Table 10. Endosulfan at 1.5ml/L gave an initial knockdown of males and was slow acting on females, but gave the best overall control. Mavrik (Yates) gave mixed results. The best control for this product was achieved at 0.1ml/L, the intermediate rate used. At the higher rate of 0.2ml/L, repellency due to additives within the formulation may be a factor causing the fruitspotting bugs to avoid contact with the sprayed nuts.

Table 11, insects exposed to 3-day-old residues, indicates that endosulfan remains active only in the short term. By Day 3 the residue appears to be ineffective and has no effect on caged bugs (see also section on residue field tests on papaw). Bulldock was superior to Mavrik (Sandoz,

Aquaflow) and gave better control. A comparison of Tables 9 & 10 indicates that the Mavrik formulation used may have influenced the results obtained.

Discussion

The data from the topical application testing indicate that fipronil is potentially the best chemical for control of fruitspotting bugs. However, because of its broad spectrum of activity and high toxicity to bees through direct contact and ingestion (Rhone-Poulenc, 1996) this pesticide was not considered for field use at this time or as a possible alternative to endosulfan.

The study has highlighted a major difference in susceptibility of the sexes to the chemicals, which is not entirely due to the differences in body weight. The work clearly demonstrates the need for larger numbers of test insects particularly females, and better estimation of discriminating doses for zero and 100% kills. This would avoid regression slopes <2 that make meaningful interpretation impossible. The limited residual activity of endosulfan, which is desirable from an integrated pest management perspective, has been confirmed. However the short effective residual period confirms the need to actively monitor for this pest. The importance of weather factors in achieving adequate field control also becomes significant in the light of such short residual activity.

Table 10. Mortality of *Amblypelta nitida* in the field following exposure to 1-day-old chemical residues on macadamia nuts. Mortality is by sex, daily and cumulative from three replicate cages containing 2 males and 2 females. Field site TFRS, spray date 15/2/1999.

Chemical	Rate (ml/L)		Days post spray 2	3	4	5	6	7	8	Cumulative mortality (%)
Control (H_20)	0	males	0	0	1	0	0	0	0	16
		females	0	0	0	0	0	0	1	16
Mavrik	0.05	males	0	0	1	0	0	0	0	16
		females	0	0	0	1	0	0	1	33
Mavrik	0.1	males	1	0	2	0	0	0	0	50
		females	0	1	2	1	0	0	0	67
Mavrik	0.2	males	0	0	1	0	0	0	1	33
		females	0	2	0	0	0	0	0	33
Endosulfan	1.5	males	0	4	0	1	0	0	0	87
		females	0	1	0	1	1	1	0	67

Mavrik is an old synthetic pyrethroid reputed to be "soft" on pollinators. It was less effective than Bulldock against fruitspotting bugs and the manufacturer appears reluctant to support trial work to progress registration of this product. Bulldock is currently registered for the control of fruitspotting bugs in macadamias and the current work confirms its efficacy. Nevertheless the macadamia industry is reluctant to use it early in the season and would prefer to with-hold its use until the macadamia nutborer also becomes a problem later in the season. Bulldock is registered for control of both pests. Within this industry and based on previous chemical usage and experience, there is a perception that the use of pyrethroids may induce secondary pest outbreaks.

In the short term or until there is evidence to the contrary, the industry may be better positioned to replace endosulfan with Bulldock for bug control, particularly if flower caterpillar, *Cryptoblabes hemigypsa* Turner, is not a problem. The effect of flower caterpillar on final harvest at least in NSW, has not been quantified. Different options both chemical and biological, should be considered for the control of nutborer that infests later in the season after the initial fruitspotting bug damage has occurred.

Table 11. Mortality of *Amblypelta nitida* in the field following exposure to 3-day-old chemical residues on macadamia nuts. Mortality is by sex, daily and cumulative from three replicate cages containing 2 males and 2 females. Field site TFRS, spray date 5/3/1999.

Chemical	Rate (ml/L)		Days Post spray 4	5	6	7	8	9	10	Cumulative mortality(%)
Control (H_20)	0	males	0	0	0	0	0	0	0	0
		females	0	0	0	0	0	0	0	0
Mavrik	0.05	males	1	1	0	0	0	0	0	33
		females	0	0	0	0	0	0	0	0
Mavrik	0.1	males	3	0	0	0	0	0	0	50
		females	1	0	0	0	0	0	1	33
Mavrik	0.2	males	4	0	0	0	0	0	0	67
		females	2	1	0	0	0	0	1	67
Bulldock	0.5	males	5	0	0	0	0	0	0	87
		females	4	0	0	0	1	0	0	87
Endosulfan	1.5	males	0	0	0	0	0	0	0	0
		females	0	0	0	0	0	0	0	0

The avocado industry is less fortunate than the macadamia industry, with only endosulfan registered for the control of both *Amblypelta* spp. A concerted effort is required to laboratory screen, field evaluate and progress registration of additional chemicals for use in this industry. The use of Bulldock or even Mavrik in avocados is contingent on the production of acceptable residue data, which has now been obtained for the former. It is anticipated that Bulldock will be registered for use in avocados in time for the 2001-2002 season.

Future studies should concentrate on monitoring for the more effective control of fruitspotting bugs, especially of females that may migrate into an orchard in a gravid state. Additional methods are required to evaluate compounds such as azadirachtin and some of the newer products reaching the market which have antifeedant and repellent properties or inhibit oviposition. For these products, lethal effects are unlikely to be apparent in both the 3-day topical application and the 7-day field testing periods that were used in this work.

10.1.2 Macadamia field trial

Methods

The trial was conducted at Diddillibah on the Sunshine Coast in a plantation of cv. '246' with a few trees of 'Own Choice' interspersed. The trial was set at one end of the block, which lay adjacent to rainforest fringing a creek, a situation that was considered to be a likely fruitspotting bug 'hotspot'. A completely randomised plot design was used with seven replicates of individual

trees separated by untreated guard trees. Treatments were applied as a high volume spray, commencing at 5.00 am when environmental conditions were 'dead calm' and finished by 8.30 am before any wind developed. Trees were 10 m high with a canopy diameter of 8 m.

Treatments applied were:

1. endosulfan (Thiodan®) @ 150 ml per 100 L water
2. beta-cyfluthrin (Bulldock®) @ 25 ml per 100 L water for the first two applications and 50 ml per 100 L water for the last two applications
3. tau-fluvalinate (Mavrik®) @ 20 ml per 100 L water
4. control – no treatment

Treatments were applied at approximately three-weekly intervals, depending on weather conditions, on 29 October 1998, 18 November, 1998, 11 December 1998 and 7 January 1999. Sprays were applied to run-off in a volume of 20 litres per tree. The dosage rate of beta-cyfluthrin was increased after two applications since damage assessments indicated that control was not being achieved at the 25 ml rate.

Thirty, fallen green nuts were collected from beneath each tree before and after spray applications and returned to the laboratory where they were dissected to detect FSB damage and assess spray efficacy. Post-treatment samples were taken at least five days after spraying to ensure all nuts that might have been damaged prior to spraying had already fallen and so had turned black and were not selected in the sample. Cage experiments had verified that damaged nuts fall within three days of being fed upon by bugs. A final assessment was carried out on 20 early-maturing nuts per tree that fell before 29 March. 1999. Damage to the husk, shell and kernel was recorded.

On 4 December and 17 December 1998, thirty-nut samples were taken from each of twelve trees in every eighth row, six on either side of the remainder of the orchard, which was treated according to commercial requirements. Three applications of endosulfan were made to this section of the orchard.

Results and Discussion

The 1998-99 season proved to be one of the most active in recent history for fruitspotting bugs. In addition, the area of the macadamia orchard chosen for the site of this trial was indeed a 'hotspot'. That fact together with the trial design, which left many trees in close proximity to the datum trees unsprayed and provided refuge for the bugs from which they could easily reinfest treated trees, resulted in continuous heavy damage in all treatments (Table 12).

Despite this, the data show that there is a definite trend in favour of the synthetic pyrethroid, fluvalinate. While the relationship of bug-damaged nuts to the natural nut drop has not been determined, it is assumed that assessment of damage to the husk of fallen nuts gives a reasonable indication of bug activity in the tree. However it does not necessarily indicate the total damage caused, since all nuts damaged before the end of December will fall.

If 66.2% of the 30 sampled nuts exhibited damage symptoms (endosulfan post-spray, 15 December), and a total of only 40 freshly-fallen nuts were present on the ground at the time of assessment, it can be assumed that even at these damage levels, the total loss to the tree would not be excessive. If it is accepted then, that the percent damage in fallen nuts was merely an indicator of bug activity, we can compare the relatively high figures in the table in a context to that indicated by the final assessment of kernel damage on early-drop nuts (Table 13), *viz.* 15% damage in the control, 11.4% for endosulfan, 5.7% for beta-cyfluthrin and 3.6% for fluvalinate. While such damage levels may still be regarded as being high, they provide an interesting comparison of the different insecticides used to produce the marketable product. The additional data from the commercial area that has been included in Table 13 is revealing, since it shows that despite the macadamia industry's perceived comfortable position with respect to the monitoring system and general pest management approach used, actual fruitspotting bug damage in the final product may still be high. The data may also indicate that in a season such as that of 1998-99 when fruitspotting bug numbers were high, monitoring frequency may need to be increased and spray intervals decreased especially when endosulfan is relied upon for control. Studies of the residual activity of the candidate insecticides revealed that endosulfan has an active life of only about four days (see Section 10.2).

Table 12: Percentage fruitspotting bug damage in fallen nuts, pre and post-spray

	Pre-spray	Post-spray	Pre-spray	Post-spray	Pre-spray	Post-spray	Pre-spray	Early drop
	26 Oct	2 Nov	16 Nov	30 Nov	10 Dec	15 Dec	22 Dec	29 Mar
Control	51.9	41.3	75.0	74.6	70.6	86.2	79.9	10.7
Endosulfan	49.0	35.7	42.8	58.6	60.0	66.2	63.0	4.3
Fluvalinate	53.3	21.9	20.9	52.8	56.4	47.6	39.5	0.7
Cyfluthrin	60.0	23.8	38.6	53.3	67.8	69.5	64.0	4.3

Table 13: Percent damage assessed on three criteria in early mature nuts – 29 March 1999

	Damage to husk	Damage to shell	Damage to kernel
Control	10.7	7.8	15.0
Endosulfan	4.3	2.8	11.4
Fluvalinate	0.7	0.0	3.6
Cyfluthrin	4.3	2.8	5.7
Commercial endosulfan	6.7	0.0	13.3

10.1.3 Avocado field trial – Woombye

Methods

The trial was conducted in a block of cv. Hass avocados situated at Woombye on the Sunshine Coast. A completely randomised plot design was used with eight replicates consisting of individual trees. Treatments were applied as a high volume spray to run-off, commencing at 5.00 am when environmental conditions were 'dead calm' and finished by 8.30 am before any wind developed. Trees were 5 m high with a canopy diameter of 5 m. High volume sprays of 15 litres per tree were applied at 1033 kPa via a tractor-mounted, PTO driven pump with a variable nozzle attachment.

Treatments applied were:
1. endosulfan (Thiodan®) @ 150 ml per 100 L water
2. beta-cyfluthrin (Bulldock®) @ 50 ml per 100 L water
3. tau-fluvalinate (Mavrik®) @ 20 ml per 100 L water
4. control – no treatment

X-77 non-ionic wetter was added to all sprays, which were applied in combination with copper oxychloride as requested by the grower to prevent infection by the fungus *Glomerella cingulata*, which causes anthracnose. Treatments were applied on 6 November 1998, 27 November 1998, 17 November 1998 and 8 January 1999.

Damage assessment was carried out on 12 March 1999 by inspecting 100 fruit per replicate and recording fruitspotting bug damage. The data were subjected to a one-way analysis of variance. On 1 April 1999, 20 fruit per replicate were assessed for the presence of live latania scale and rated according to the description in Table 2. Fifteen terminals per replicate were assessed for the presence of tea red spider mites and these were also rated according to the description in Table 4.

As part of the trial, the β-cyfluthrin treatments were utilised to obtain samples for the establishment of maximum residue levels (MRLs) so that the chemical's progression to registration in avocados could be facilitated. For this, duplicate samples were taken from two treated trees on completion of the final spray and then at 7, 14 and 21 days post-treatment. All fruit was placed in plastic bags appropriately labelled, and stored in a deep freeze until it was forwarded to a Brisbane laboratory for residue analysis.

Results and Discussion

Fruitspotting bug activity on the avocado property was high with the cv. Fuerte sustaining severe damage at around 20%, despite regular applications of endosulfan. The cv. Hass is regarded as being less susceptible to fruitspotting bug damage, largely because of its thicker skin, but such resistance is often an illusion. Under unsprayed conditions or where sprays are missed, or in the absence of a more attractive crop such as Fuerte nearby which may act as a diversion, Hass is likely to suffer severe damage.

In this trial, probably because the Fuerte provided a more attractive target (large trees and an acknowledged preference), the Hass trees were subject to far less damage than were the Fuerte, for whatever reason – less attractive, more open situation, some distance from natural breeding areas and more effective sprays suppressing immigrant bugs within the whole block. Nevertheless, the unsprayed trees suffered more damage than any of the insecticide treated trees, including the endosulfan treatment.

Tau-fluvalinate gave the best control and trees treated with this insecticide suffered the least damage, being significantly better than β-cyfluthrin, the next best treatment. Both of these were significantly more effective than endosulfan, which was not significantly different from the control (Table 14).

Even though endosulfan has been a favoured fruitspotting bug control in a range of crops, especially avocados because of its value in IPM systems, its residual activity against fruitspotting bugs has always been questionable. Our recommendations have always been that its frequency of application should be governed by a grower's on-site experience, the cultivars grown and the proximity of the orchard to rainforest or other breeding areas. Under the conditions of this trial where all insecticide applications were set on a three-weekly schedule, endosulfan was clearly not up to the task. Neither did it perform well in the commercial Fuerte block where sprays were applied fortnightly. This is not to say that there is no place for endosulfan in the avocado system since, if the industry was to switch solely to synthetic pyrethroids, which might then be used in excess of six times in a season, unusual outbreaks of latania scale and tea red spider mites would result. On the other hand the intermittent use of the pyrethroids would most likely suppress all caterpillar pests including leafrollers, thus doing away with specific sprays of chlorpyrifos. While endosulfan is still available, under severe fruitspotting bug pressure its use should be integrated with that of the pyrethroids to minimise their adverse effects on the beneficial fauna that helps to suppress many other potential pest species.

Table 14: Analysis of damage assessment on fruit examined from each replicate for each treatment – average number of fruit damaged per 100 - Hass avocados

	Endosulfan	B-cyfluthrin	Tau-fluvalinate	Control
Transformed mean	5.5c	1.4b	0.14a	7.3c
Actual mean	5.87	1.62	0.38	8.38

Transformation = Log x + 0.5; LSD (5%) = 0.250. Means followed by the same letter are not significantly different.

Assessments to measure the likely effect of all of the treatments on scales and mites showed that under the use pattern imposed in this trial there is no particular threat of an outbreak of these pests as a result of the limited use of pyrethroids (Table 15). However, it is noted that the base level incidence of latania scale before the trial commenced, was low. Excessive use of these chemicals in orchards where scale populations are moderate could easily precipitate an outbreak.

Despite four applications of pyrethroid sprays to half the avocado block used in the trial, predatory insects were common over all treatments. Good numbers of *Stethorus* spp., a small black ladybird that feeds on mites, and *Mallada signata*, a green lacewing that is a general predator on mites, lepidopterous eggs, scales etc., were observed throughout the orchard on the date of the scale and mite assessment.

Results for the MRL trial carried out in conjunction with the efficacy trial for Bayer Australia indicate that after two weeks, β-cyfluthrin residues have diminished to the limit of detection, 0.01 mg/kg. These data, when added to past trial data and that from other trials conducted in 1999-2000, will enable the registration of β-cyfluthrin for fruitspotting bug control in avocados. That is expected to be accomplished in 2001.

If the future banning of endosulfan causes use patterns for the pyrethroids to alter from being occasional to regular, alternative strategies will have to be adopted in order to prevent adverse developments in the orchards. Tactics such as spraying only hotspots or purposely-planted trap

trees could limit the area of application and the sphere of adverse influence of broad-spectrum chemicals. With our increasing knowledge of the bugs' habits, such options are real.

It is clear from the results of this trial and also of that conducted in macadamias, that either of the synthetic pyrethroids tested provides superior fruitspotting bug control to endosulfan. This conclusion is supported by data obtained in experiments conducted to test the residual activity of the alternative chemicals compared with endosulfan, reported elsewhere in this document. This statement should be considered in relation to other comments made regarding the management of such chemicals.

Table 15: Ratings of live latania scale on fruit and tea red spider mite on leaves of Hass avocados used in the fruitspotting bug control trial – assessed 1 April 1999.

Block No.	Rep. No.	Endo.		Mavrik		Bulldock		Control	
		mites	scales	mites	scales	mites	scales	mites	scales
1.	1	1	1	1	1	1	1	1	1
	2	1	1	3	1	1	1	1	1
2.	1	1	1	1	1	1	1	1	1
	2	2	1	2	1	2	1	1	1
3.	1	1	1	2	2	1	1	1	1
	2	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1
	2	1	1	1	1	2	1	1	1

Live scales on 20 fruit per tree
Rating

1 average of 0-3 per fruit 1
2 average of 3-10 per fruit
3 average of 10-20 per fruit
4 average of > 20 per fruit

Average no. mites on leaves with mites, on 15 terminals per tree
Rating

1 < 10 per leaf on leaves with mites
2 10-20 per leaf on leaves with mites
3 20-50 per leaf on leaves with mites
4 > 50 per leaf on leaves with mites

10.1.4 Avocado field trial - Palmwoods

A neglected Hass avocado orchard at Palmwoods on the Sunshine Coast was used to compare the efficacy of pyrethrum, fipronil and endosulfan. Fipronil had demonstrated variable and inconsistent results in laboratory assays, but information supplied by representatives of the manufacturing company Aventis, suggested that it was worth investigating in the field.

Methods

Trees for each treatment including an unsprayed control were selected randomly throughout the orchard, with untreated trees between them to prevent drift. Most of the trees in the orchard remained untreated which, along with the natural breeding area adjacent, providing a large reservoir of fruitspotting bugs that continually exerted pressure on the chemical treatments under trial.

Treatments applied were:

Endosulfan - 150 ml per 100 litres water
Fipronil - 40 ml per 100 litres water
Pyrethrum/avocado oil - 10/14 ml per 100 litres water
Control - no spray

Treatments were applied to five trees per treatment at the rate of 10 litres of spray per tree on 25 November 1999, 14 December 1999, 24 December 1999 and 20 January 2000. No other sprays were applied outside of this period, and it is conceded that some of the recorded damage may have been inflicted either before or after spraying ceased. However, all treatments including the controls should have been damaged equally. This may account for the high levels of damage noted even in the best treatments since the orchard was subject to very heavy fruitspotting bug pressure.

Damage assessments were conducted on 14 April 2000 by randomly harvesting 50 fruit from each of the replicate trees. Hail damage that occurred in November confused the damage determination, so that every fruit was peeled with a potato peeler to confirm actual fruitspotting bug damage and to distinguish it from hail damage.

The damage data were subjected to a one-way analysis of variance.

Results and Discussion

The damage levels recorded for the unsprayed control trees and also for the endosulfan treatment indicate how severe the overall infestation was at this site for the season
The best treatment was fipronil with a mean damage level of 19.2% but this was not significantly different from the pyrethrum/oil treatment at 29.6% (Table 16). The endosulfan treatment was no better than the unsprayed control. This result is somewhat perplexing, since endosulfan normally provides acceptable control. It would certainly be expected under normal circumstances to be more effective than pyrethrum. However, we know little about the effectiveness of pyrethrum in the field against fruitspotting bugs and it may well be that the treatment applied is as good as or better than endosulfan. Laboratory data indicated that it could be effective against the bugs in the laboratory for more than 10 days (see section on Pyrethrum experiments). More field data are required to confirm its efficacy under commercial conditions and no recommendation will be made for its commercial use until these results have been verified.

Table 16: Mean percent damaged fruit for each insecticide treatment on avocados at Palmwoods, 1999-2000

Treatment	Mean percent FSB damage
Fipronil	19.2 a
Pyrethrum/avo. oil	29.6 a
Endosulfan	60.4 b
Control	62.0 b

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

14.2 Residual activity of selected chemicals against *Amblypelta* spp.

Introduction

Using a series of field experiments we set out to assess the impact of insecticides not only in terms of their residual activity and efficacy but also in terms of their compatibility within the confines of an integrated pest management program.

In November and December 1998 a field experiment was performed using young papaw plants growing in the field at Marooochy Research Station to evaluate the residual activity of three insecticides (Plate 6). The trial was designed to complement the earlier set of chemical bioassays, which established the LD95's for a range of technical grade insecticides. From these tests it was concluded that synthetic pyrethroids like fluvalinate (Mavrik®) were more effective than the currently registered products such as endosulfan and beta-cyfluthrin. We then needed to evaluate the commercial formulations in the field. To this end an experiment was designed to evaluate how effective the insecticides were at various time intervals after spraying. In other words, if a spray was applied today, how effective would the insecticide be in one week's time? Insecticides were also evaluated in terms of their effect on natural enemies. Using a series of knock down trials we were able to identify and quantify those beneficials affected by an insecticide application.

Method and materials

In the laboratory, banana-spotting bugs, *Amblypelta lutescens*, readily fed on papaw, whereas fruitspotting bugs, *Amblypelta nitida* exhibited no interest in the plant whatsoever as a food source. For this reason, banana-spotting bugs were used to evaluate the efficacy and residual activity of selected insecticides. All spotting bugs were conditioned by feeding them exclusively on papaw in the laboratory for a minimum of one week prior to the commencement of the experiment.

Eight week-old papaw seedlings were planted in the field between the 13 and 16 October 1998, at a spacing of 1m within the row and 2m between the rows. Maroochy Research Station farm staff maintained the plants throughout the experiment ie. fertilising, irrigation and weed management. The trial was set up as a randomised block design with two treatments, chemical x time, in three blocks. Forty-eight plants were used in the trial (Table 17 & Plate 7) with a buffer of two rows separating the experimental plants from the outside edge of the planting.

Plate 7: Spraying papaw plants to evaluate the efficacy and residual activity of Thiodan®, Bulldock® and Mavrik® against fruitspotting bugs

Three insecticides were evaluated: Thiodan® (active constituent endosulfan, applied at 150mL/100L), Bulldock® (active constituent beta-cyfluthrin, applied at 50mL/100L) and Mavrik® (active constituent tau-fluvalinate, applied at 20mL/100L). All experimental treatments were compared with a control, which received water only. Treated plants were sprayed to point of run off with a 500ml home and garden trigger sprayer. Each sprayed plot contained between two and three plants and received a total of 5ml of spray. Treatments were applied on the 20 November 1998 when the plants were between 55 and 65 cm in height.

Table 17: Experimental design of the papaw chemical residue experiment. Each combination identifies a single plot and outlines the treatment (*i.e.* endosulfan (Thiodan®), cypermethrin (Bulldock®), B-cyfluthrin (Mavrik®) and Control) and the time after spraying when the bugs were caged on the plant.

Block One			
Control, Day 14	Mavrik, Day 0	Thiodan, Day 7	Bulldock, Day 4
Thiodan, Day 4	Control, Day 7	Bulldock, Day 0	Mavrik, Day 14
Mavrik, Day 4	Thiodan , Day 14	Control, Day 0	Bulldock, Day 7
Mavrik, Day 7	Control, Day 4	Thiodan, Day 0	Bulldock, Day 14
Block Two			
Mavrik, Day 14	Thiodan, Day 4	Bulldock, Day 0	Control, Day 7
Bulldock, Day 14	Control, Day 0	Thiodan, Day 7	Mavrik, Day 4
Bulldock, Day 7	Control, Day 4	Thiodan, Day 14	Mavrik, Day 0
Bulldock, Day 4	Mavrik, Day 7	Thiodan, Day 0	Control, Day 14
Block Three			
Thiodan, Day 0	Bulldock, Day 4	Control, Day 7	Mavrik, Day 14
Mavrik, Day 4	Control, Day 0	Thiodan, Day 7	Bulldock, Day 14
Thiodan, Day 14	Mavrik, Day 0	Control, Day 4	Bulldock, Day 7
Thiodan, Day 4	Control, Day 14	Mavrik, Day 7	Bulldock, Day 0

Zero, four, seven and fourteen days after the treatments were applied four spotting bugs were caged on the plants in each experimental plot, so that for each treatment and at each time interval a total of twelve spotting bugs was used. The cages consisted of a nylon mesh bag, 800mm x 700mm with mesh diameter <1mm, and sealed by tying its base onto the rim of a 5 litre plastic pot. The pots with the base cut off, were placed over the plant just after spraying. Soil was mounded up around the base of the pot to seal the cage. Two bamboo stakes, each 1m long, were placed inside the cages to prevent the cage from touching the plant (Plate 8). Spotting bug mortality was recorded four days after the bugs were placed in the cages.

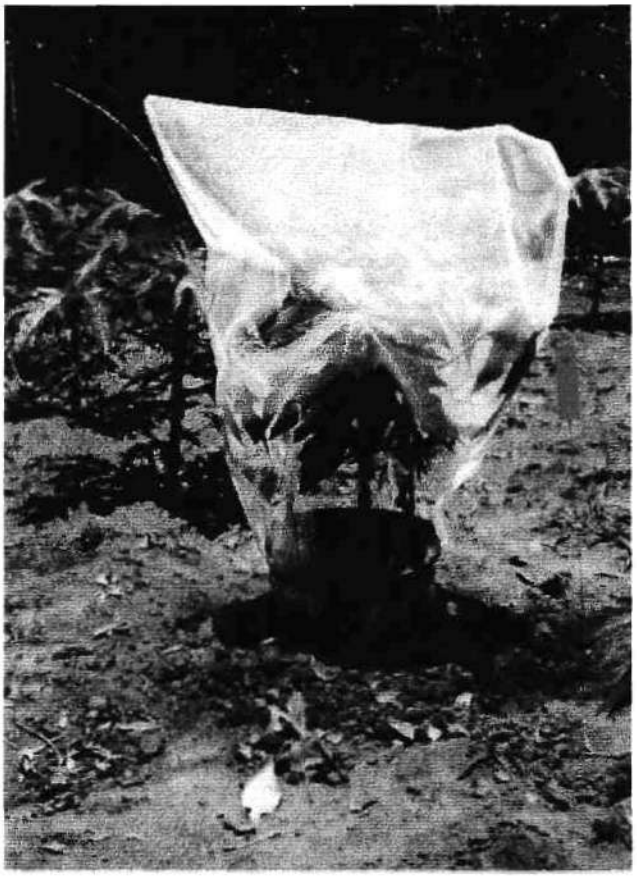


Plate 8: Cage used to contain fruitspotting bugs on papaw seedlings during the chemical residue experiment.

Results and discussion

Analysis of variance was used to assess the effect of chemicals ($P<0.001$), time ($P<0.001$) and their interaction ($P<0.01$), and all were significant. On Day 0, fruitspotting bug mortality was significantly higher in all chemical treatments compared to the control (Figure 14). It is worth noting however that two bugs survived the Mavrik treatment, perhaps as a result of poor coverage! On Day 4, there was no difference between the Control and Thiodan treatments, Bulldock was slightly more effective than those two and Mavrik was superior to Bulldock . On Day 7 there was no difference between the Control, Bulldock and Thiodan treatments, confirming suspicions concerning the lack of significant residual activity of Thiodan, but also revealing the

surprisingly short residual activity of Bulldock. Mavrik was still effective at this time, causing 66% mortality. Mavrik was obviously the best in that it provided the longest residual activity, but after 14 days it too had lost most of its activity, killing only 20% of the caged bugs. This longer residual activity is an obvious bonus especially if calendar sprays are applied every two or three weeks, as it will protect the crop to a greater degree and for much longer than the alternatives. Endosulfan on the other hand had the shortest residual activity. This too can be advantageous if it is intended to release beneficials shortly after spraying, as will be appreciated from the results in the following section. These data are based on a specific set of weather conditions, some of which may have influenced the results. It is important to note that some or all products may have performed better or lasted longer if a synergist, sticker or wetting agent had been used in conjunction with the insecticide.

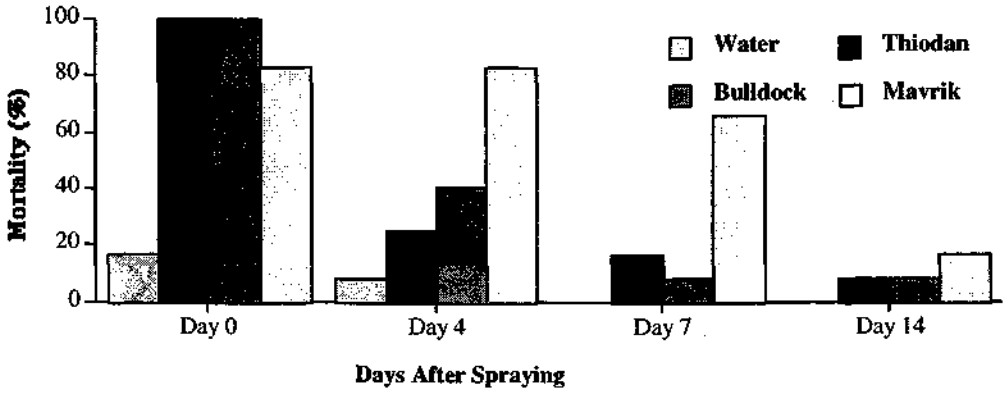


Figure 14: Fruitspotting bug mortality recorded four days after caging on sprayed papaw plants. n=12 bugs per treatment at each time interval.

10.3 Endosulfan MRL determinations for custard apples

Introduction

Fruitspotting bugs are a major pest of custard apples and as with other crops, frequent insecticide applications are required to prevent excessive damage. One of the other major pests of the crop is the citrus mealybug, which can be difficult to control if pesticides that disrupt its natural enemies are introduced into the system. Endosulfan generally does not disrupt the parasitoids and predators that can provide excellent biological control of the pest. However, if endosulfan becomes unavailable, for whatever reason, likely alternatives could disrupt the natural control. One outcome of the recent review of endosulfan conducted by The National Registration Authority, was that maximum residue levels (MRLs) must be determined for all crops in which endosulfan is used or its use would no longer be permitted. Since there was no MRL set for custard apples and the continuing use of endosulfan was required, trials were conducted to obtain the relevant information.

Methods

Two trials were conducted from March to June 2000, one at Maroochy Research Station and the other at the Tropical Fruits Research Station at Alstonville.

Maroochy: Endosulfan at 2 and 4 mls per litre water was applied to two custard apple trees per dose rate at 15 litres of spray mixture per tree. Three applications were made at fortnightly intervals commencing on 3 March 2000. The weather conditions at the time were recorded. As soon as the spray had dried after the final application, a minimum 2 kg sample of fruit was taken, labelled and placed in a freezer. Similar samples were taken 7, 14 and 28 days later, the last being on 1 May 2000.

Alstonville: The same procedure as above was followed with the first spray applied on 28 April 2000. The final sample was taken on 23 June 2000.

All of the stored samples were transported to Indooroopilly for analysis by the Organic Chemistry Laboratory of QDPI.

Results and discussion

Details of the treatment procedure, weather conditions and the residue analysis report have been forwarded to The National Registration Authority for consideration and determination of an MRL and withholding period for endosulfan in custard apples. It is expected that this should be a formality and that endosulfan will continue to be available to the custard apple industry for the control fruitspotting bugs.

10.4 Impact of endosulfan on the resident insect complex in macadamias

Introduction

Endosulfan has been recommended and used for fruitspotting bug control for many years. Apart from providing reasonable control of the pests, experience has shown that it is much less disruptive of natural enemies than are most other insecticides. Since it is used in many crops for against a range of insect pests, this characteristic seems somewhat paradoxical. Why, if it kills such a range of insects, does it not have a severe impact on beneficial species? We were interested to see what was the sequence of events with respect to endosulfan's impact generally, and especially the initial impact on the resident insect community of a single application to a tree crop.

Methods

Early in the 1998/99 season the impact of one spray of endosulfan to a macadamia orchard was assessed by collecting the arthropods that were killed (Figure 16). Immediately prior to spraying 12 boxes each 30 x 45 cm, were placed under 10 trees - a total of 120 boxes. The trees were then sprayed with endosulfan at the recommended rate (Thiodan®, at 150 ml/100 litres water).

Approximately 24 hours later the boxes and their contents were collected and all arthropods were sorted and identified to at least Order level.

Results

The extent of the mortality inflicted on the arthropod fauna by the endosulfan spray was surprising and indeed, a revelation. Many beneficial arthropods including ants, lacewings, spiders, parasitic flies and wasps were killed (Figure 15). These beneficials attack both major and minor pests and are especially responsible for keeping some of the minor pests under control, particularly scales and mites. The spray also knocked out some key pollinators and this obviously has important implications if endosulfan is applied to various crops at flowering for flower caterpillars or as a pre-emptive strike against fruitspotting bugs before flowering is complete. In this particular orchard a total of 885 arthropods was collected in the sample units. Only five of these individual insects were fruitspotting bugs - two 1st instars, one 2nd instar and one male and one female. While these findings indicate that endosulfan can initially be very toxic to a range of species, the previous study concerning its short residual activity perhaps provides a clue as to why it can often be successfully integrated into IPM systems.

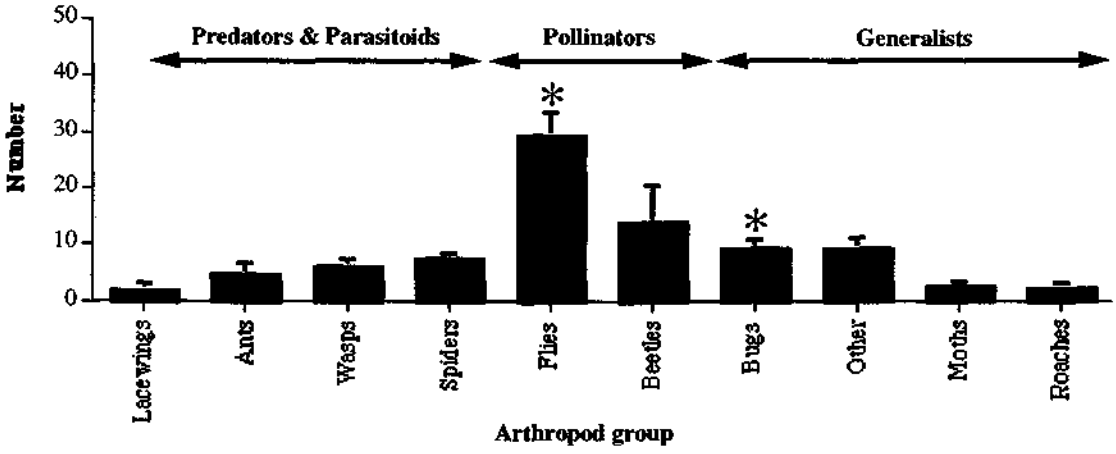


Figure 15: Number (Mean ± Standard Error) of arthropods collected beneath ten macadamia trees following an application of endosulfan. The category 'Bugs' includes all types of true bugs, not just fruitspotting bugs! The asterisks indicate that some fly and bug species were parasitoids or predators.

10.5 Residual effect of chemicals on beneficial species

Introduction

The general aim in modern pest management is to develop integrated systems that incorporate essential chemical sprays along with conservation biological control. Some chemical applications are usually necessary to manage those pests that are not subject to good biological control within a cropping system, or that are very mobile and move ahead of potential natural enemies. Fruitspotting bugs fall into the latter category, for although they suffer considerable natural mortality to eggs and immature stages in their natural breeding habitats, the very mobile adult bugs, which also cause most of the damage to orchard crops, are the survivors of the hazards of

the early developmental period and escape to migrate into orchards. In the absence of alternatives, there is no option at this time but to apply insecticides to control them. The need to conserve natural enemies within the orchard ecosystem to preserve some balance, creates a dilemma. On the one hand, a very damaging pest has to be controlled with chemicals while some potentially serious pests are very well suppressed by natural enemies. The balance is often very fragile and the slightest disruption may propel the minor pest into the major pest category. Endosulfan has been used for fruitspotting bug control because it fits the requirements of being a reasonably effective fruitspotting bug killer while maintaining a balance with respect to the 'minor' pests.

The effect of a single endosulfan spray to a macadamia orchard in terms of the spectrum and number of all insects knocked down by that spray has been described elsewhere in this report. The results were somewhat of a surprise since it has generally been assumed that the 'softness' of endosulfan is related to its fairly benign effect on beneficial species. It should be noted though that there is little or no experimental evidence for arriving at that assumption. In order to discover how endosulfan produces the effects it does and also to compare it with potential alternatives, experiments were conducted in the laboratory to compare the residual effect of three insecticides including endosulfan, on selected beneficial species.

Methods

The technique used was a modification of one developed over half a century ago (Munger 1940). The method has since been modified and has been used to evaluate the residual toxicity of pesticides, while minimising pesticide fumigation effects in the relatively confined cells used to contain the test insects. Pesticide treated leaves that have been exposed to natural weathering conditions were used as the substrate in the test cells (Morse *et al.*, 1986).

Prior to building the equipment, a QDPI statistician was consulted to ensure that the possible randomised arrangement for each experiment would be statistically valid. Although the equipment was designed and built to the specifications of Morse *et al.* (1986), a few modifications were made. The capacity of the apparatus was half that of the original so that instead of holding 144 munger cells it contained only 72 (Plate 9). A Manrose ducted centrifugal fan kit (SFCFD200S Cat. No. Fan 0382) was used to force a continuous stream of fresh air into a rear plenum chamber that provided a constant equal pressure to all cells. Nalgene plastic tubing was used to connect the munger cells to the central airstream exiting the plenum chamber (Plate 10). Test insects were sourced through 'Bugs for Bugs' at Mundubbera. Three representative species were tested - adult *Aphytis lingnanensis*, a minute parasitic wasp of California red scale; adult *Cryptolaemus montrouzieri*, a native ladybird beetle that preys on mealybugs and soft scales; larval *Mallada signata*, a native green lacewing that preys on a variety of soft-bodied insects including mites, scales, aphids and lepidopterous eggs and young larvae.

To maintain a series of similarly weathered residues over time for each of the chemicals tested, leaves of the umbrella tree, *Schefflera actinophylla*, were sprayed to run-off on Day 0. The leaves were cut into sections to fit the 'sandwich' of the munger cells in which the test insects were caged. Moistened tissue paper was laid beneath the section of leaf in the sandwich to help retain its freshness and reduce the dehydrating effect of the airflow. Leaves treated with each insecticide

that were not used on Day 0 were stored with their petioles immersed in separate buckets of water in a glasshouse in full sun, to allow weathering of residues without their being washed off by rain. The treated umbrella tree leaves fulfilled the requirements of the experiment well and retained vitality and turgidity for over a month.

The test leaves were sprayed with the following treatments:
1. β-cyfluthrin (Bulldock®) @ 0.5 mls/litre water
2. fipronil (Regent®) @ 0.5 mls/litre water
3. endosulfan (Thiodan®) @ 2 mls/ litre water
4. tebufenozide (Mimic®) @ 0.1 g/litre water
5. control - no treatment

For *Aphytis*, a minimum of 50 test insects was used per cell with five replicates per run. A range of 55-80 was used because of their small size and fragility and the impossibility of accurately counting them without inflicting injury. The final number was determined after the experiment was terminated. For each of *Cryptolaemus* and *Mallada*, five insects were used per cell, with 10 replicates per run. *Aphytis* and *Cryptolaemus* were fed via honey smears to the wall of the cells and food for *Mallada* was supplied in the form of eggs of the grain moth, *Sitotroga cerealella*. For each run, the cells were rearranged according to a predetermined computer-generated randomised plan. Assessment of percent mortality was conducted at 24 hours after initial exposure and for some treatments especially fipronil at 48 hours, since this chemical was often slow to show any effect. The data were subjected to a one-way analysis of variance.

Results and Discussion

***Aphytis*:** β-cyfluthrin, fipronil and endosulfan were all very toxic to *Aphytis* exposed immediately after treatment on Day 0 giving 100%, 92.1% and 98.9% mortality respectively (Table 18). On Day 1, β-cyfluthrin and endosulfan exhibited the same level of toxicity, but that for fipronil fell to 22.7%. β-cyfluthrin continued to kill 100% of the test insects until the tests were terminated after 27 days. After 7 days, the mortality recorded for endosulfan fell to levels comparable to that of the controls but curiously, the toxicity of fipronil increased to 69.8% for the 24 hour assessment and 100% after 48 hours. Fipronil continued to kill 96% of the test insects up to 27 days post-treatment.

***Cryptolaemus*:** β-cyfluthrin killed 92% of the test insects on each of Day 0 and Day 1 (Table 19). After 7 days, it was still toxic causing mortality of 84% but after 14 days this had declined to 32%. By Day 23 it had no effect and was no different to the control. Fipronil had no effect on *Cryptolaemus* and the slight mortality recorded at Day 7 was no different to that for the control. Endosulfan killed 12% of the test insects on Day 0, but thereafter had no effect. Tebufenozide had no direct effect on the beetles and the possibility of detrimental effects further along the life cycle as has been reported for some other insect growth regulators against coccinellids, was not investigated in these experiments.

***Mallada*:** β-cyfluthrin killed 100% of the test insects on Day 0 and Day 1. By Day 11 mortality was 52%, and remained high at 66% on Day 14 (Table 20). Fipronil was relatively non-toxic on Day 0 but increased in toxicity over time to 56% on Day 1, 76% on Day 11 and 86% on Day 14 .

This reflects its effect on *Aphytis* where the toxicity increased with time, the reverse of what would normally be expected. Endosulfan and tebufenozide had no effect at all on any of the exposure days against *Mallada*.

Table 18: Mortality of *Aphytis lingnanensis* adults over time and assessed 24 hours after exposure, resulting from residues of various chemicals.

Chemical	Day 0	Day 1	Day 7	Day 14	Day 23	Day 27
β-cyfluthrin	100 b	100 c	100 c	100 b	100 b	100 b
Fipronil	91.7 b	22.7 b	97.8 c	100 b	98.1 b	95.9 b
Endosulfan	98.9 b	97.5 c	29.0 b	not tested	not tested	not tested
Tebufenozide	10.4 a	4.6 a	14.8 b	not tested	not tested	not tested
Control	7.1 a	4.9 a	26.4 a	16.0 a	7.3 a	4.8 a

Numbers followed by the same letter are not significantly different.

Table 19: Mortality of *Cryptolaemus montrouzieri* adults over time and assessed 24 hours after exposure, resulting from residues of various chemicals.

Chemical	Day 0	Day 1	Day 7	Day 14	Day 23
β-cyfluthrin	92.0 c	92.0 b	84.0 b	32.0 b	4.0 a
Fipronil	2.0 a	0.0 a	4.0 a	0.0 a	0.0 a
Endosulfan	12.0 b	0.0 a	0.0 a	0.0 a	0.0 a
Tebufenozide	2.0 a	0.0 a	4.0 a	0.0 a	0.0 a
Control	0.0 a	0.0 a	12.0 a	0.0 a	4.0 a

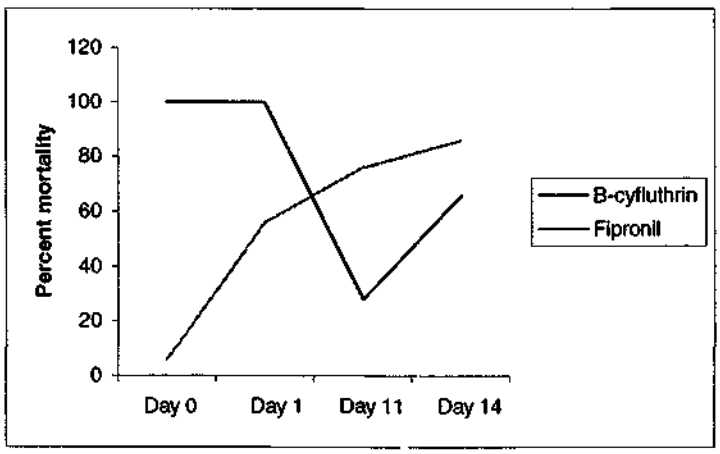
Numbers followed by the same letter are not significantly different.

Table 20: Mortality of *Mallada signata* larvae over time and assessed 24 hours after exposure, resulting from residues of various chemicals.

Chemical	Day 0	Day 1	Day 11	Day 14
β-cyfluthrin	100 b	100 c	28.0 b	66.0 b
Fipronil	6.0 a	56.0 b	76.0 c	86.0 c
Endosulfan	0.0 a	0.0 a	0.0 a	0.0 a
Tebufenozide	0.0 a	0.0 a	0.0 a	0.0 a
Control	0.0 a	0.0 a	0.0 a	0.0 a

Numbers followed by the same letter are not significantly different.

Figure 16: Comparative mortality of *Mallada* as β-cyfluthrin and fipronil residues age.



Summary

As expected, β-cyfluthrin was extremely toxic to all of the beneficial species tested. The most sensitive was *Aphytis*, which suffered virtually 100% mortality for more than a month after the leaves had been treated. Endosulfan was toxic to *Aphytis* initially but after seven days, it had no effect at all, reflecting its effect on fruitspotting bugs in the field as reported above. Endosulfan had no effect at all on either *Cryptolaemus* or *Mallada*. *Cryptolaemus* was unaffected by all of the chemicals tested except for β-cyfluthrin, the toxicity of which fell to low levels after 14 days and non-significant levels after 23 days.

Tebufenozide had no effect on any of the test species but fipronil, while it was not toxic to *Cryptolaemus*, it was extremely toxic to *Aphytis* and showed moderate to extreme toxicity to *Mallada*. The results for this chemical are puzzling since it showed an inverse relationship with time against *Aphytis and Mallada* ie. the relative toxicity against these insects increased with the age of the residues instead of decreasing (Figure 16). The explanation for this is not known, but further studies should be conducted to confirm this and clarify the real effects that it might have on a crop ecosystem. Its safety for *Cryptolaemus* at least, is good news for the custard apple industry, which needs to protect predators and parasites that control mealybugs, especially *Cryptolaemus*.

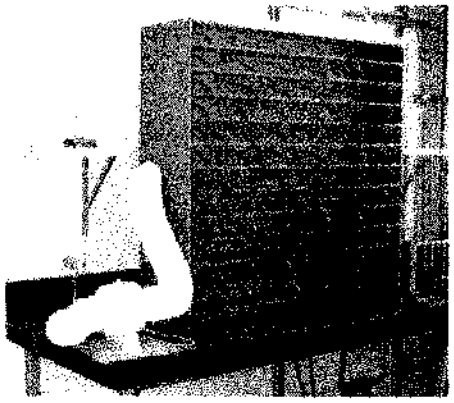


Plate 9: Plywood holding rack designed to provide uniform air circulation to each of the 72-munger cells

Plate 10: Modified munger cell used to evaluate the residual toxicity of pesticides to beneficial insect species while minimising pesticide fumigation effects

11. Pyrethrum/neem studies

Organic growing represents only a small component of all horticultural industries, but fills a niche that enables a certain number of growers to make a living while providing a product that some consumers desire. The production of organic produce is governed by certain restrictions on what can be used in the production system and especially in regard to pest and disease control. Often the organic alternatives allowed are unsuitable for the production of quality fruit that possesses the high standards required by most of the retail market and consumers. The botanical insecticides pyrethrum and neem extract, which are allowed in organic systems, do have some useful attributes that may contribute to fruitspotting bug management not only in organic systems, but also within conventional fruit production systems. During the course of this project the opportunity was taken to assess the efficacy of a pyrethrum/neem mixture and pyrethrum/oil mixtures against fruitspotting bugs in two macadamia crops and in an avocado crop.

Methods

11.1 Macadamias – Boreen Point

An 'organic' orchard consisting of 800 macadamia trees at Boreen Point was not sprayed for two months after nut-set. During this time a substantial population of *Amblypelta nitida* had infested the trees and the population included a mix of adults and all nymphal instars. The manager of the orchard eventually acted on the advice of a private consultant and sprayed it with pyrethrum (Pyrethrum SF® - Kendon) at the rate of 200 ml per 100 litres of water, with no effect. A follow-up spray at 300 ml per 100 litres of water also had no effect. A third spray at 400 ml per 100 litres water was then proposed and since we had no information on the activity of pyrethrum against fruitspotting bugs, we set out to collect some data by spreading tarpaulins under several trees of two different cultivars, before the last spray at 400 ml per 100 litres water.

Results and Discussion

The higher rate of pyrethrum was effective in knocking adult and nymphal fruitspotting bugs out of the trees within 15 minutes of application. An average of about four adult bugs and eight nymphs of all stages per tree, were retrieved from the drop sheets. Along with the fruitspotting bugs, representatives of many different orders of insects were also collected. These included native cockroaches, fruit flies, ants, lacewings, crickets, parasitic wasps, beetles, caterpillars, moths etc., and demonstrates the wide spectrum of activity that pyrethrum has. Despite its certification for use in organic production systems, this particular attribute may make it appear to be a less than ideal candidate for use in IPM systems. However, used at lower rates and in combination with synergistic compounds other than piperonyl-butoxide (see next section) it may have some potential, particularly if it can be targeted at fruitspotting bug 'hotspots'. Endosulfan as will be seen elsewhere in this document, exhibits similar acute toxicity to a wide range of insect species, and still plays a crucial role in IPM situations.

11.2 Macadamias – Blackbutt

At Blackbutt, macadamia trees were grown organically and fruitspotting bugs and green vegetable bugs were controlled during the season with applications of pyrethrum mixed with neem extract. The grower had experimented with different mixtures and dosage rates to the extent that he had been able to reduce the effective dosage rate to one that he considered was also economical. He was keen to provide the information to us and to also have us conduct some experiments to verify his findings and refine the technique.

Methods

Towards the end of the season when the macadamia shells had hardened and fruitspotting bugs were no longer a threat to the viability of the crop, the grower allowed *Amblypelta nitida* to build up in numbers in the trees. On 15 March 1999, tarpaulins were placed under five trees that were then treated via an air-blast sprayer with a spray mixture with the following components:

12.5 mls of 50% pyrethrum
19 mls of canola oil
100 mls of neem extract (Nutri-neem)
100 litres of water

Pyrethrum has little insecticidal effect when applied alone and compounds called synergists, are added to increase its activity. Traditionally, piperonyl-butoxide has been used for this purpose, but that chemical is not allowed for use in organic systems. Organic oils have also been shown to have synergistic effects and so canola oil was added to the mixture to fill this role. A very low spray volume was applied to only one side of the trees. The number of bugs knocked down onto the tarpaulins was counted.

Results and Discussion

All stages of fruitspotting bugs were knocked down onto the tarpaulins and died, the first to drop out within five minutes being nymphs, which all belonged to instars 1, 2 and 3. After ten minutes adults began to fall out of the trees, and no more dead bugs of any developmental stage appeared after 15 minutes. More dead bugs may have been recorded had the whole tree been sprayed from both sides. A total of 25 bugs was collected from the tarpaulins (7 adults and 21 nymphs) as a result of what was in effect, a very 'superficial' spray.

The result of this small experiment was impressive and although the costs per tree would be 50% higher than for endosulfan, they are not prohibitive, especially for an organic grower for whom there are few practical alternatives. The relative costs of the treatments are detailed in Table 21. Subsequent laboratory experimentation revealed that the addition of neem had very little effect on final bug mortality and that avocado oil, which has been shown to have insecticidal properties of its own (Rodriguez-Saona *et al.*, 1998) could be used as the synergist. Huwer (1997) found that neem was toxic to the nymphs of *A. lutescens*, but it was very slow acting and achieved 100% mortality only after exposure of the nymphs for 10 weeks. It is obviously not an option for use in

crops and especially against the more resistant adults for which rapid knockdown is required to counter continuous immigration.

Table 21: Relative costs of pyrethrum/neem and endosulfan

	Approx. cost per tree	Approx. cost per tree
	15 litres/tree spray volume	10 litres/tree spray volume
Endosulfan	$ 0.57	$ 0.34
Pyrethrum/neem	$ 0.85	$ 0.55

The following experiments were performed in the laboratory to explore the potential of pyrethrum and various additives as controls for fruitspotting bugs.

11.3 Laboratory bioassays

Experiment 1

The promising results observed in the field experiment demonstrated that the application of pyrethrum, either in combination with neem or alone for fruitspotting bug control, need not be considered as having application only to organic orchards. Endosulfan has been shown in the experiments detailed elsewhere in this report to have a relatively short residual life. The effective life of the organic mixture would be of interest to us in the context of its potential as an alternative to endosulfan, particularly if the residual activity was at least two days. A laboratory experiment was undertaken to investigate this aspect, though it was acknowledged from the outset that the results may not be directly applicable to the field because of the known effect of UV light on the rate of breakdown of pyrethrum.

Methods

On 3 March 1999 a mixture of pyrethrum/neem/avocado oil was made up according to the recipe above except for the substitution of avocado oil for canola oil. In addition to this mixture an experimental chemical, YRC 2894, which is related to imidacloprid, was also tested at a dosage rate of 100 ml per 100 litres of water.

Fresh French beans were dipped in solutions of each of the test chemicals and placed in plastic containers used to rear fruitspotting bugs. Five, second-instar nymphs of *Amblypelta lutescens* were placed into each container and the treatments replicated three times. Three replicates of five nymphs on untreated beans were included as a control. A new cohort of nymphs was placed into each container each day for as long as mortality was recorded. Water was made available via a cotton wick inserted into a filled plastic vial. Observations were carried out at 30 minute intervals for the first 2 hours of exposure and thereafter once each day.

Results and Discussion

After placement in the cages with the treated beans, not all bugs approached the beans to walk or feed on them immediately so there was little effect for the first hour or so. In the pyrethrum/neem treatment, one nymph was affected after 15 minutes but only after some time and acclimatisation

to the cage conditions did others come into contact with the treated beans. After 90 minutes four nymphs in each of the three cages had succumbed, having fallen on their backs and did not recover. After two hours all of the bugs in all of the cages were affected with the 'jitters' and did not recover. After 24 hours five new nymphs were added to each cage and after 24 hours all were dead. Similarly, new recruits added after another 24 hours all died within 12 hours. A further cohort added five days after treatment produced final mortalities of 5/5, 4/5, and 3/5 per cage after 24 hours. No further tests were carried out. Although the mortalities relate to early instar nymphs exposed to unweathered residues, these results are encouraging and suggest that the treatment may be as effective as endosulfan, certainly within a day or so of treatment. However, as with the conventional alternative chemicals tested as replacements for endosulfan, pyrethrum also has a broad spectrum of activity and is not 'soft' on beneficial species immediately after application.

Experiment 2

Methods

On 21 September 1999 four replicates of four adult *A. nitida* were caged with two fresh French beans that had been treated as follows:

1. fipronil - 0.4 mls (200 SL) per litre water
2. pyrethrum - 0.125 ml (50%) plus 2 ml avocado oil per litre water
3. pyrethrum - 0.125 ml (50%) plus 2 ml avocado oil plus 2 ml neem (Nutri-neem)
4. control - no treatment

Assessments of mortality were made at 3 hours and 24 hours. For treatments in which high mortality was recorded, fresh bugs were added after 24 hours for the first two days and then after six days. The experiment continued for six days.

Results and Discussion

After three hours 100% of the bugs in the pyrethrum/avocado oil treatment had died. No bugs in the fipronil treatment had died, neither did they show any ill-effects. The same was true for the pyrethrum/neem/oil treatment but all of the bugs in this treatment had retreated to the top of the containers, away from the treated beans. None had walked on or fed on the beans. No bugs were affected in the control (Table 22).

After 24 hours, 31.25% of the bugs in the pyrethrum/neem/oil treatment had died, while only 12.5% were dead in the fipronil treatment. Fresh bugs placed in the former treatment all died within 3 hours. After another 24 hours, there was no more mortality in the fipronil treatment but that in the pyrethrum/neem/oil treatment had risen to 43.75%. Bugs were not added to the pyrethrum/oil treatment again until 27 September, six days after treatment. Meanwhile, mortality in the pyrethrum/neem/oil treatment reached 100% but that in the fipronil treatment did not change. No mortality was recorded in the controls.

Table 22: Mortality at 24 hours after bugs were caged up to 6 days after treatment

Treatment	Day 0	1 day post-treat.	2 days post-treat.	6 days post-treat.
Fipronil	12.5	12.5	12.5	12.5 (cumulative)
Pyrethrum/avo. oil	100	100 (fresh bugs)	100 (fresh bugs)	100 (fresh bugs)
Pyrethrum/neem/avo. oil	31.25	43.75	68.75	100 (cumulative)
Control	0	0	0	0

Pyrethrum plus avocado oil killed fruitspotting bug adults for at least six days when they were exposed to residues of the mixture on beans in the laboratory. The bugs were all killed very quickly, usually in less than three hours. On the other hand, when neem oil was added to the mixture, mortality was reduced in the short term, possibly because of the claimed repellent effect of the neem keeping the bugs away from the treated beans. Hunger in combination with a reduction in the repellent effect after a few days, probably enticed the remaining live bugs to venture on to the beans to feed, where they were killed by the pyrethrum. The fipronil treatment was extremely disappointing. Even taking into account the fact that it is often slow-acting, the final level of mortality was negligible on this occasion.

Experiment 3

The performance of the pyrethrum/avocado oil mixture in the previous test prompted its being tested at a lower dosage rate, to see if it could be used effectively at a more economical rate. Fipronil was again included, as was abamectin (Avid®).

Methods

One male and one female *A. nitida* along with three third instar nymphs of *A. lutescens* comprised each of five replicates that were caged on beans treated with the following on 3 February 2000:

1. pyrethrum (0.0125 ml) plus avocado oil (0.2 ml) per litre water, plus wetter
2. pyrethrum (0.00625 ml) plus avocado oil (0.1 ml) per litre water plus wetter
3. fipronil (Regent®) - 0.5 ml per litre water plus wetter
4. abamectin (Avid®) - 0.5 ml per litre water plus wetter
5. control - no treatment

Assessment of mortality was made at 24 hour intervals, but observations were also made at varying intervals between the major assessments to determine how quickly the acute residual toxicity of the treatments decreases over time. In treatments where 100% mortality was recorded fresh bugs were placed in the cages after each 24 hours, except for the third exposure, when the second exposure spanned a weekend.

Results and Discussion

After one hour, mortality was 100% in the full rate pyrethrum/oil treatment and 60% in the half rate pyrethrum/oil treatment. After 24 hours, mortality had also reached 100% in the half rate treatment. In the abamectin, fipronil and control treaments, mortality was zero. 92% of fresh bugs added to the pyrethrum treatments one day later, died within 30 minutes of contact with the beans. At 24 hours there was 100% mortality. After four days only 12% mortality was recorded in the original bugs placed in the abamectin treatment and 48% in the fipronil treatment. These figures did not change over the following four days, but by Day 11, 80% of the bugs in the fipronil treatment had died, while the abamectin had no further effect and the control mortality was zero. All of the bugs added to the two pyrethrum treatments up to Day 11 died. The experiment was terminated at this time due to deterioration in the quality of the beans. The data suggest that these treatments may have continued to kill bugs for several more days if the life of the beans could have been prolonged.

The above data were very encouraging, but it must be remembered that these experiments were conducted under laboratory conditions in the absence of direct sunlight. It is well known that pyrethrum breaks down rapidly under ultra violet light and it apparently has very little insecticidal activity after one day in the field. However there may be areas of a tree that are protected and shaded where deposits might last longer. Alternatively, it might be worth trying to protect the spray through the addition of some of the newer sunscreens. A small experiment conducted by caging bugs on treated avocado fruit in the field showed pyrethrum activity did not extend beyond one day. However, a replicated field trial in avocados that compared pyrethrum with fipronil and endosulfan showed that when pyrethrum was applied as a series of sprays throughout the season in a program similar to that currently used for endosulfan, reasonable control was achieved (see section on field trials). If it was to be alternated with an occasional spray of endosulfan, then fruitspotting bug control might be commercially acceptable.

General Conclusions

There is no doubt that pyrethrum is very toxic to fruitspotting bugs of all stages, except the eggs. A well-applied spray could be expected to kill all of the bugs with which the spray initially comes into contact and others that contact the spray residue within the ensuing 24 hours. The addition of neem to the original mixture seems to have conveyed little if any advantage, since subsequent combinations with avocado oil alone proved just as effective. The data show that avocado oil or canola oil and probably any organic oil are effective synergists for pyrethrum.

Further trials need to be conducted to confirm the results achieved in the avocado field trial with pyrethrum/avocado oil and to further assess its usefulness in commercial orchards. Organic growers would definitely find the treatment useful since in the absence of other organically acceptable controls, this one at least offers some hope of limiting fruitspotting bug damage, if not of preventing it totally.

12. Fruitspotting bug habitat

12.1.1 Habitat surveys

Introduction

The hosts of fruitspotting bugs have been studied over a number of years (Waite and Huwer, 1998) and those studies continued throughout the course of this project. Several new hosts were identified and they have been added to the original host list.

In addition to this, the vegetation surrounding selected macadamia, avocado and lychee orchards was surveyed for the occurrence of known fruitspotting bug hosts and plant species that were common to all areas, so that currently unidentified potential fruitspotting bug hosts might be indicated.

Methods

The vegetation surrounding eight orchard blocks that are highly susceptible to fruitspotting bug attack and have a history of severe damage was surveyed, and individual tree and shrub species identified. These identifications were made by a contracted local biologist who was well-acquainted with the flora of the area.

Results and discussion

The complete list of flora identified from areas adjacent to selected 'at risk' orchards on the Sunshine Coast appears in Appendix 2. Known fruitspottting bug host trees were confirmed present in all areas, with at least five and up to eleven different species. Most common amongst these were *Glochidion, Elaeocarpus, Ficus, Alphitonia, Neolitsea* and *Cryptocarya* species. However, there were several species common to all areas that have not been recorded as fruitspotting bug hosts at this time, but which have been suspected as such. These are various species of *Eucalyptus* that generally dominate the forests in areas where fruitspotting bugs are a severe problem, especially on the Sunshine Coast. *E. microcorys* (tallow wood), *E. grandis* (flooded gum), *E. intermedia* (pink bloodwood), *E. pilularis* (blackbutt) were all common to 'native habitat' areas. While fruitspotting bugs can frequently be found on the other plant species, the numbers generally noted do not seem to account for the numbers that invade orchards. Concentration and aggregation of individuals through migration into smaller orchard areas obviously increases the population per unit area over that in the natural breeding areas, but other sources of bugs appear to be implicated than just the common known host species. Since the eucalypts tend to dominate bordering forest areas and the incidence of other hosts in terms of absolute numbers is low, eucalypts are still considered to be possible fruitspotting bug hosts.

If *Eucalyptus* species are breeding hosts, then the terminal growth of the trees is most certainly the target for bug feeding. The 1998/99 and 1999/2000 seasons on the Sunshine Coast were very wet, and most forest trees and shrubs were in an almost continuous state of flush. In these two seasons extremely high numbers of fruitspotting bugs migrated into orchards and caused severe damage. There does appear to be a good correlation between wet springs and subsequent severe

fruitspotting bug outbreaks in those seasons. It is suspected that the link may be the flushing behaviour of *Eucalyptus* spp. under such conditions. However, there is little likelihood of being able to confirm *Eucalyptus* spp. as being significant breeding hosts for fruitspotting bugs because of the height of the trees and the probable sparse occurrence of the bugs over a wide area. There are records though of at least *A. lutescens* breeding on *E. camaldulensis* in the Ord River area of W.A., and in the Solomon Islands *A. cocophaga* is a severe pest of plantation *E. deglupta.*
In 1999-2000 one grower at Maleny decided not to undertake any pest control following the staghorning of the entire orchard and an expected low production. The trees did in fact produce a good crop, but fruitspotting bug damage in the absence of control exceeded 80%. This orchard is surrounded by eucalypt forest and the grower was of the strong opinion that it was source of the heavy infestation of bugs. He had previously removed windbreaks composed of *Eucalyptus dunii*, believing that they contributed to the fruitspotting bug problem.

Outcomes

Since the alternative hosts of fruitspotting bugs are so numerous and can be found within easy flying distance of most orchards, there is little that can be done to use this knowledge in a positive way as far as direct control of the insects is concerned. It can however be used to indicate how severe fruitspotting bug infestations might be if orchards are established in certain locations. It will also indicate where hotspots and edge effects are most likely to occur so that monitoring can be concentrated in such areas.

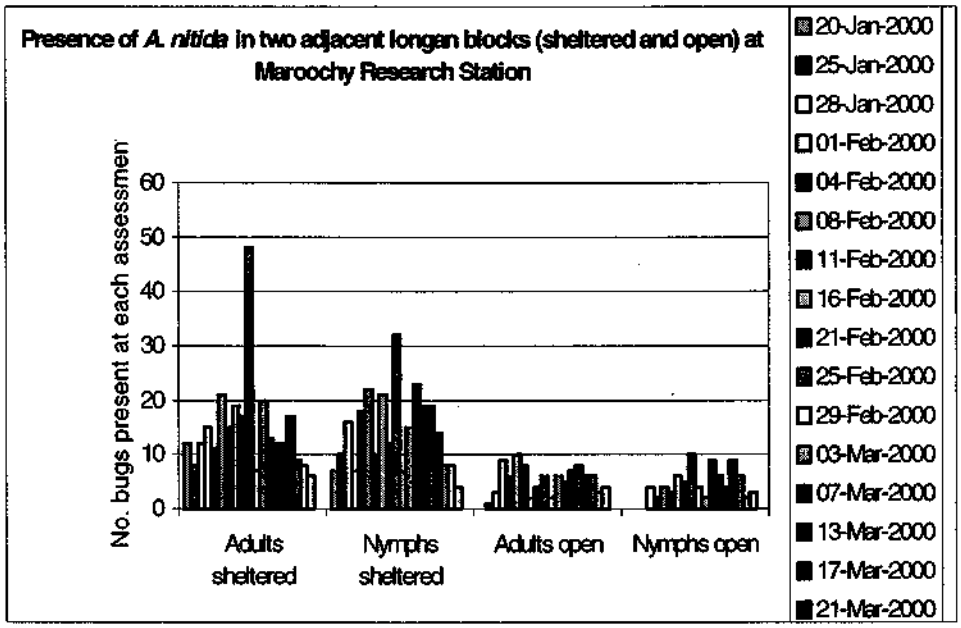
12.1.2 Fruitspotting bug relationship with windbreaks

Whereas previously windbreaks were relatively common in orchards, many of them have been removed because of concerns that they harboured or attracted various pests, especially fruitspotting bugs and *Monolepta.* Surveys of orchards revealed that there was no strong correlation of fruitspotting bug damage with windbreaks of various types and when interviewed, most growers did not consider that windbreaks were responsible for higher damage levels. However, where belts of scrub have been left to act as windbreaks, there was a definite correlation with fruitspotting bug populations in the orchard and subsequent damage. In these situations, the increased infestation levels most likely arose due to the combined effects of the shelter provided and the presence of alternative hosts outside of the orchard, giving rise to the typical hotspot. Such a situation can be seen at Maroochy Research Station, where two separate blocks of longans are grown side by side, but separated by about 30 metres. Block 1 is bounded entirely on the southern side by native scrub dominated by *Eucalyptus* spp. but also containing several known fruitspotting bug hosts. Block two is bounded on the south by more open vegetation that contains few individual fruitspotting bug hosts. Every year, Block 1 hosted a larger fruitspotting bug presence than Block 2. This was reflected in the early loss of fruit in that block as well as in the total bug count (Figure 17).

Outcomes

Purpose-planted windbreaks generally do not contribute to the fruitspotting bug problem, although they may combine with other extraneous factors to contribute to the creation of an area of higher bug activity than might otherwise occur. For example, where a windbreak connects with the end boundary of a patch of scrub that opens onto cleared land, it may create a suitable environment in that corner for bugs, which would not be the case if the orchard boundary abutted the cleared land. Windbreaks should be considered in the design of sampling and monitoring systems so that such situations are not overlooked.

Figure 17: Effect of adjacent forest acting as breeding habitat, windbreak and shelter for fruitspotting bugs infesting longans



12.2 Differences in the canopy characteristics of orchard trees and the associated activity by fruitspotting bugs

Introduction

Canopy management in avocados, lychees and macadamias has been a major issue for growers, particularly as inter-tree and inter-row spacing has decreased in established crops. Pest and disease control becomes more difficult as trees increase in size, tree maintenance and crop harvesting is physically more challenging, and yields can decline as light penetration through the canopy is progressively reduced. Growers and researchers have speculated that in crops such as avocados, trees with dense, closed canopies are more prone to fruitspotting bug activity than those with a sparser, more open habit. Studies were undertaken in north Queensland to ascertain whether the level of fruitspotting bug damage in tree fruits was a function of canopy density by manipulating the canopies of carambola and mango trees in two separate experiments on Walkamin Research Station. The results of this work were intended to supplement other investigations on canopy effects, so that growers could make sound decisions concerning the need to manage tree structure. Canopy manipulation was not, however, being contemplated as a specific control option for fruitspotting bugs. Rather, if trees with different canopy densities showed different susceptibilities to bug activity, a more targeted approach to monitoring bug activity may result.

Methods

The initial canopy manipulation experiment employed 11 year-old carambola trees, originally planted in four blocks of 20 trees each and five varieties per block. Prior to treatment (which occurred immediately prior to flowering), all trees possessed dense, heavy canopies with some foliage touching the ground. Six of these trees (3 cv. Thai Knight and 3 cv. Fwang Tung) were retained in this form as the **closed canopy** treatment. Six other trees of the same varieties had their centres substantially thinned and hanging branches skirted to about 1m above the ground. These trees represented the **open canopy** treatment. Each of the two carambola varieties were represented in each of the four blocks, with the same treatment in the two varieties occurring in adjacent trees in two blocks and opposing treatments in the two varieties occurring in adjacent trees in the other blocks. The amount of light penetrating vertically through the canopies of each treatment tree was measured with a light meter (Gossen Mastersix) at the time that monitoring for fruitspotting bug activity commenced. Monitoring for bug damage and presence occurred fortnightly from 20 January 1998 to 30 March 1998. Fifteen panicles and three fruit per panicle were inspected per tree on each occasion.

The second canopy manipulation experiment was undertaken in a block of 60 mango trees of the variety Kensington Pride. The block of 60 trees was divided into four for the purpose of the experiment, with each **closed** or **open** treatment block (of 15 trees) diagonally opposite the same treatment block. Prior to the summer growth flush, the canopies of all trees in the **open** treatment were thinned (in a similar fashion to the carambolas), while all trees in the **closed** treatment were left untouched. Light penetration was measured vertically and horizontally through the canopy at the time monitoring commenced. Five trees in each treatment block were selected for monitoring bug activity,

with trees selected from both the outside and centre of each block (Figure 25). Trees were monitored for bug presence and damage from 9 February 1999 to the end of that year, with assessments generally occurring weekly through the main growth periods (flushing and fruiting) and at longer intervals during other times. Fifteen panicles were assessed per tree; the resulting data were essentially cumulative. Fruit counts were undertaken on the monitored trees at the conclusion of the experiment. Through February 1999, temperature data loggers were placed in a number of the treatment trees to compare differences in canopy microclimate between **closed** and **open** canopies.

All data were subjected to standard statistical tests to determine the significance of any differences between treatments.

Results

Carambolas. The amount of midday light penetrating the canopies of treatment trees averaged 1178.3±136.1 lux in the **open** treatment and 424.1±96.8 lux in the **closed** treatment (Figure 18).

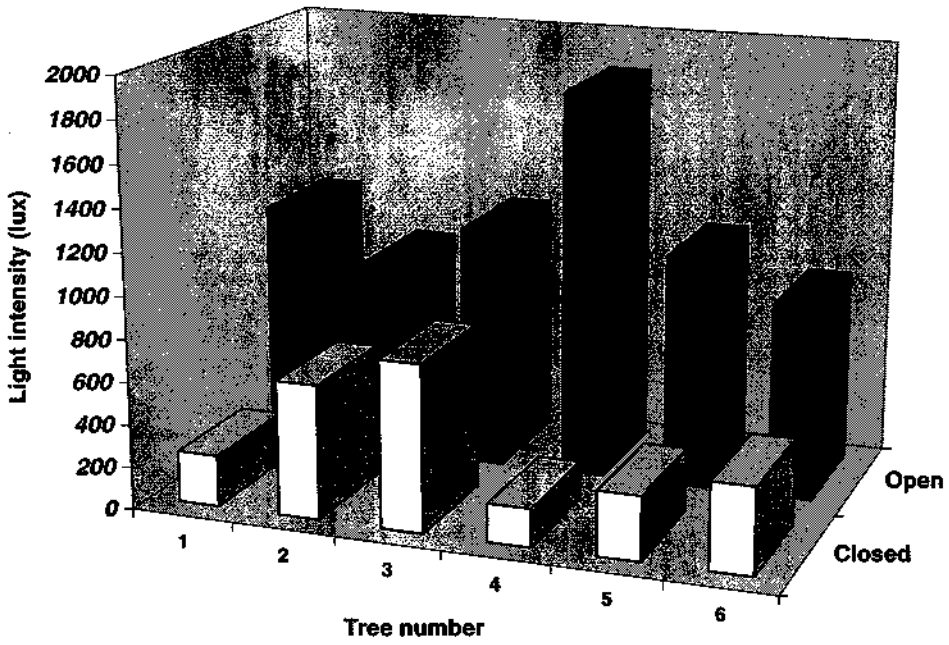


Figure 18. The average amount of light (in lux) penetrating the open and closed canopies of individual carambola trees in January 1998.

There was no statistical difference in panicles with bug-damaged fruit if trees are compared on the basis of light penetration. In fact, trees with **open** canopies had an overall 27.97% of panicles with bug-damaged fruit compared to 28.22% in trees with **closed** canopies. On only the first monitoring occasion was bug damage significantly lower in the **open** treatment. However, there was a significant difference in the level of bug damage sustained by the different varieties, with cv. Thai Knight more prone to attack (Figure 19). Fruit on trees of cv. Thai Knight showed more bug damage in **closed**

canopies than in **open** ones on five out of six occasions, with the difference being substantial on three of these occasions (Figure 19). There were negligible differences in the levels of bug damage sustained in trees of the two canopy types in cv. Fwang Tung. In general, bug-damaged fruit tended to accumulate on trees as the crop matured, then declined as fruit ripened and fell. Of the numbers of fruitspotting bug adults or immature stages (including egg remnants) encountered, 38.5% were recorded in trees of cv. Thai Knight with **closed** canopies (Figure 19).

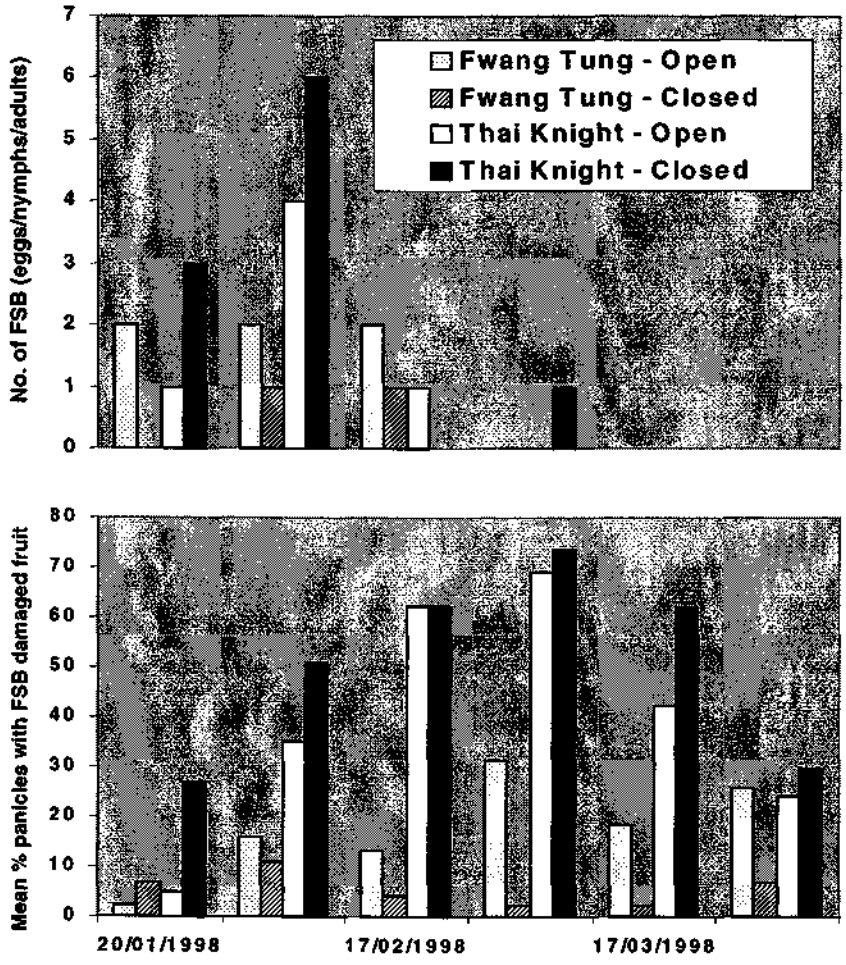


Figure 19. Fruitspotting bug damage to fruit on panicles of carambola trees with open and closed canopies and the numbers of bugs (all stages) associated with the damage.

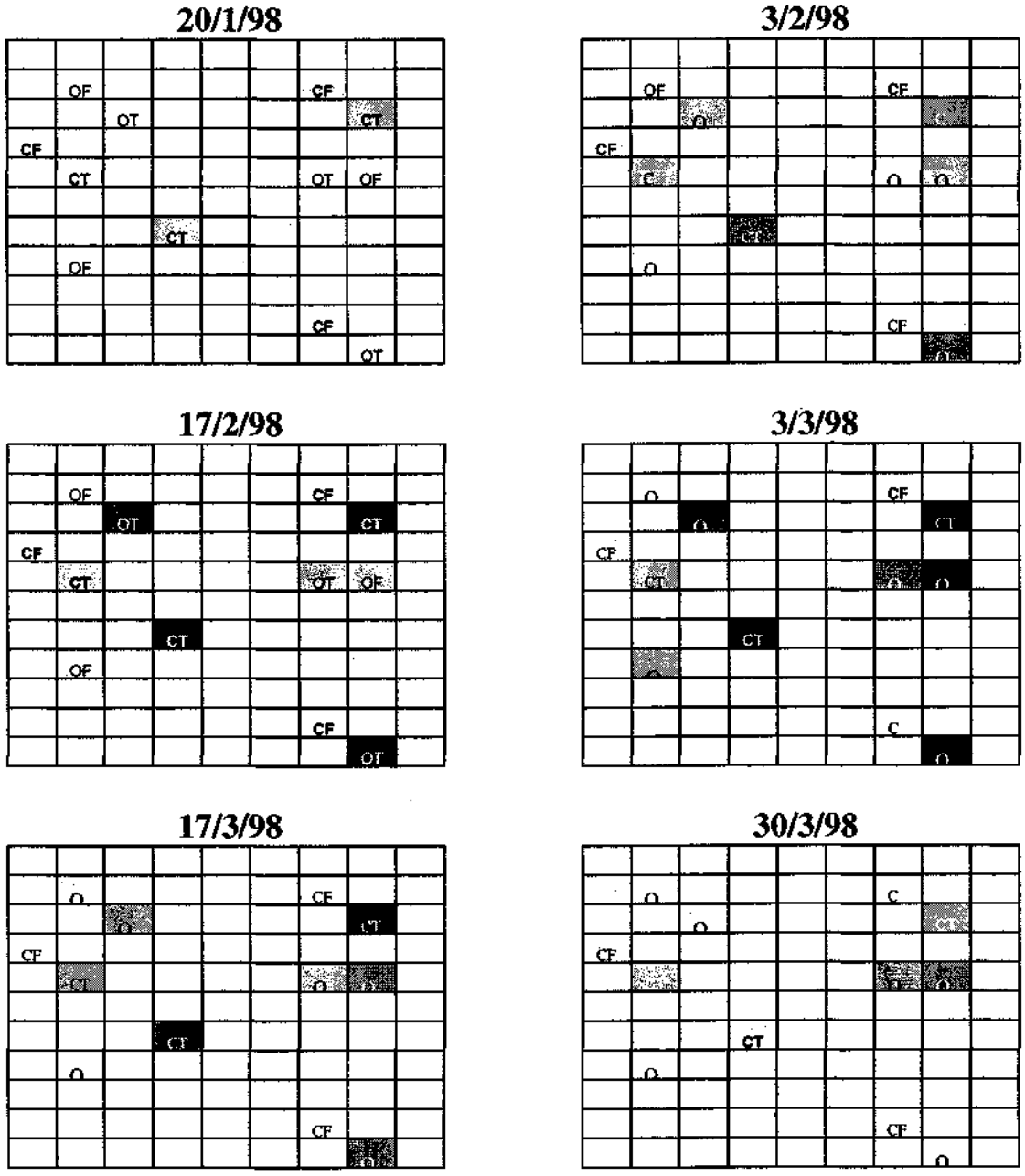


Figure 20. Changing patterns of fruitspotting bug damage to carambola fruit in orchard trees with open and closed canopies during 1998. C=closed, O=open, T=Thai Knight, F=Fwang Tung.

Mangoes. The average midday temperature in mango trees with **open** canopies was up to 4°C higher than that in trees with **closed** canopies during a 2-week period in February (Figure 21).

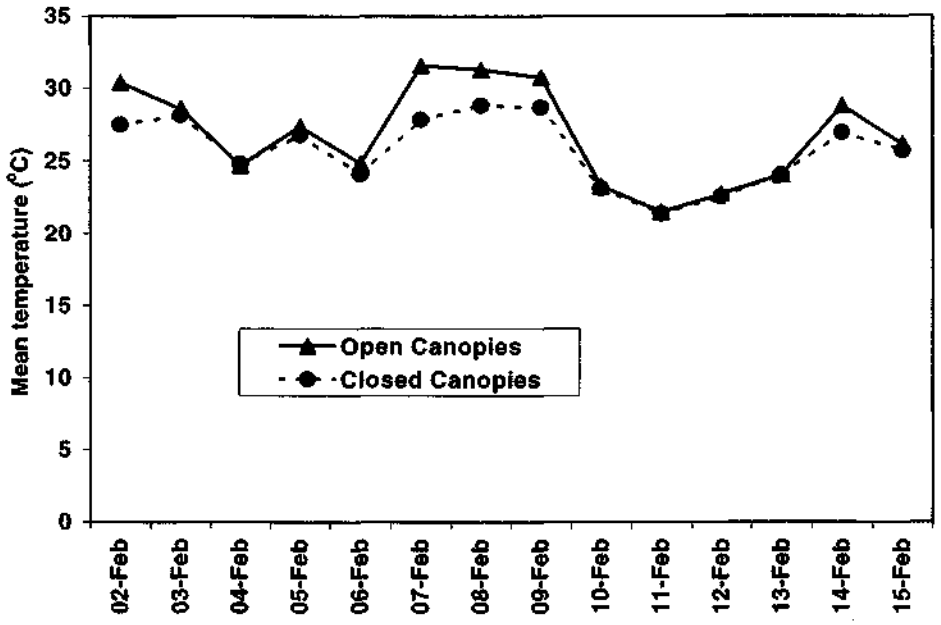
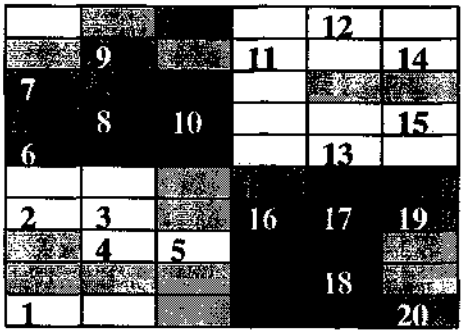


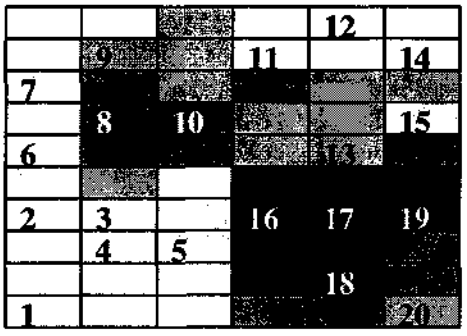
Figure 21. Differences in temperature in mango trees with open and closed canopies.

Light measured ***vertically*** through canopy – Light meter



	0 – 499 lux
	500 – 999 lux
	1000 – 1999 lux
	2000 – 3999 lux
	> 4000 lux

Light measured ***horizontally*** through canopy – Camera f-stop



	1/15 sec
	1/30 sec
	1/60 sec
	1/125 sec
	1/250 sec

Figure 22. Canopy light penetration through mango trees measured by two different methods. Trees 1-5, 11-15 = open canopies, & Trees 6-10, 16-20 = closed canopies.

Differences in light penetration between canopy types were greater when measured vertically, as opposed to horizontally (Figure 22). While fruitspotting bug damage varied considerably between trees over the experimental period, on four out of eight occasions during the summer growth flush period there was substantially more damage in total to panicles in **closed** canopies than in **open** ones (Figure 23).

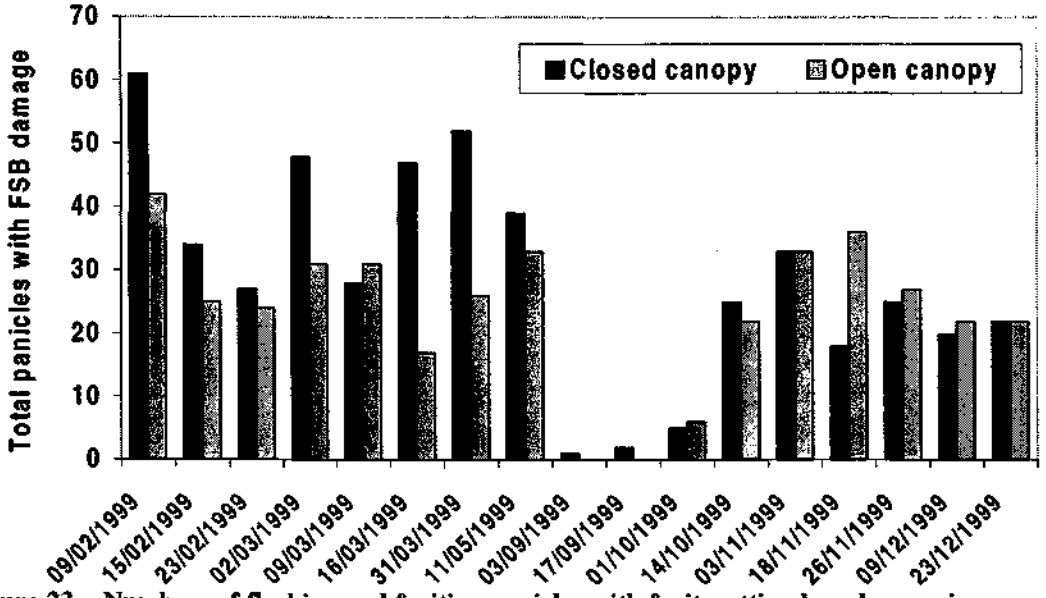


Figure 23. Numbers of flushing and fruiting panicles with fruitspotting bug damage in mango trees with open and closed canopies.

Further analysis of these data indicated that in the **closed** canopy situation more trees had greater numbers of damaged panicles per tree than in the **open** canopy treatment (Figure 24). Monitoring later in the year during the fruiting period showed negligible difference in bug damage levels between treatments (Figure 23). By the end of the experiment the numbers of mature fruit per tree varied considerably and were generally low, but the averages were similar for trees with **open** ($\bar{x}$ = 11.8) and **closed** ($\bar{x}$ = 12.9) canopies.

Discussion

It is experimentally difficult to demonstrate different responses by fruitspotting bugs to tree canopies of different density. Bug activity tends to be variable throughout orchards, with a range of physical and environmental factors influencing the way bugs behave. Despite this, the results from the experiments reported above have provided some indication of the canopy type preferred by fruitspotting bugs. Trees with canopies that are completely closed and have minimal light penetration appear in general, to sustain higher levels of fruitspotting bug damage than those with a more open habit, particularly where favoured varieties are concerned. This is a phenomenon that has been observed for other insect pests in tree plantations (Togashi, 1990; Folgarait *et al.*, 1995). Differences in the levels of bug damage sustained in trees with different canopy characteristics appeared to relate to the numbers of fruit or panicles attacked per tree, rather than some trees being completely unattractive with no damage recorded at all. Perhaps in trees with open canopies bugs feed longer on individual fruits or panicles, rather than changing feeding

site frequently, or they may spend less time in an individual tree than would otherwise be the case. Open canopies may provide less shelter than closed ones, and increased vulnerability to predation may result in less time spent feeding. However, the data presented above clearly indicate that factors such as varietal preference can overwhelm the effects of canopy density. The same is probably true of tree proximity to sources of bug incursions ie. hotspot situations. Irrespective of the type and uniformity of canopy possessed by trees in a single variety orchard, there will be orchard characteristics that affect bug behaviour and result in higher levels of bug damage being recorded in some trees

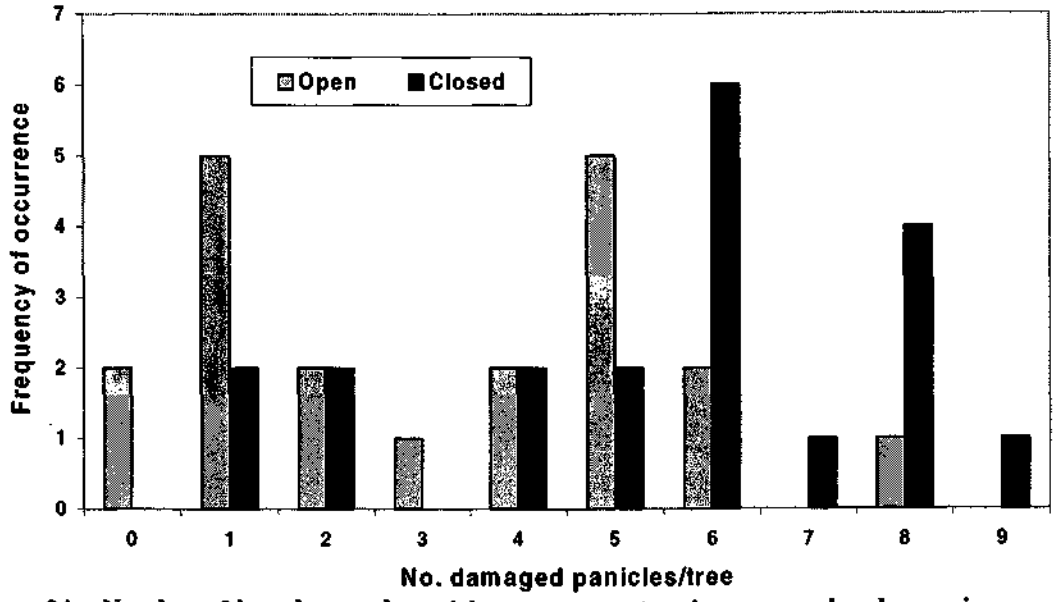


Figure 24. Number of bug-damaged panicles per mango tree in open vs closed canopies across the orchard.

Outcomes

While there may be an overall reduction in the level of bug damage in trees with open canopies no individual tree appears less likely to sustain some bug activity than any other. This means that an entire orchard would still need to be treated with insecticide if damage thresholds are reached, unless known hotspots or susceptible varieties are a specific feature of an orchard. Nevertheless, trees with sparse, open canopies are more amenable to effective spray coverage (Travis *et al.*, 1987) than trees with dense canopies, so that if all the agronomic factors associated with open canopies are favourable (Corelli and Sansavini, 1989; Jackson, 1989), bug control may be another factor for growers to consider when assessing canopy management needs. Apart from this, crop varieties that are highly attractive to bugs, such as the avocado variety Fuerte, may have a role in dense canopy form as monitoring or decoy trees, to provide an indication of the timing and level of bug activity and reduce the intensity of attack on the main crop.

13. Relationships between crop phenology and fruitspotting bug activity

Introduction

There are individual growers, consultants and researchers with a good knowledge of fruitspotting bug activity in particular crops (Waite *et al.*, 1993) but no definitive data have been collected previously in crops such as macadamias or avocados, which track crop development through an entire season and document the intensity and patterns of associated bug activity. Such data would help to answer a number of questions that need to be addressed if controls for bugs are to be properly targeted and pesticide use rationalised. When do bugs have most impact on a crop? How sustained and intense is damage through a cropping cycle? What are the patterns of attack in trees within a crop? How does chemical intervention impact on bug activity and crop yield? What are the opportunities for a reduction in chemical use, and is an increase in monitoring intensity and frequency necessary to achieve this?

Preliminary work in a carambola crop on the Atherton Tableland in 1991-93 indicated that controls for fruitspotting bugs during the main cropping period in February-March could be curtailed after most of the fruit had attained maximum size, as there was not sufficient damage from then on to justify further spraying. In addition, bug damage during the later crop in May-June was inconsequential and did not warrant insecticidal intervention. Chemical control of fruitspotting bugs is usually either prophylactic or triggered by a damage threshold being reached and detected during monitoring. Windows of reduced susceptibility or the incidence of light and inconsequential damage have rarely been considered in crops subject to fruitspotting bug activity, but these factors need to be investigated so that more detailed knowledge can help drive the development and adoption of IPM in these crops. The studies described below followed fruitspotting bug activity in macadamia and avocado crops at a number of sites I north Queensland, under various levels of chemical intervention.

Methods

Sampling sites.

Macadamias (Kairi) – This plantation contained about 950 established trees of the varieties 344 and 741, interplanted. The plantation was bordered by cattle pasture and by a steep vegetated bank that fell away to the edge of the Barron River. There was minimal management of this plantation in 1997/98, with no pesticides used. In 1998/99, only three insecticidal sprays were applied throughout the cropping period.

Macadamias (Atherton) – This plantation was located 1 km from the town of Atherton, and contained 2000 established trees of a single variety, 344. The plantation was bordered by cattle pasture, ti tree and sugar cane. Pest monitoring was undertaken in this plantation by the owner, which resulted in a minimal number of insecticide applications during the season.

Avocados (Malanda) – This orchard was situated about 4 km from Malanda on a steep north-facing slope. The orchard contained about 400 trees, predominantly of the varieties

Fuerte and Hass. The orchard was bordered by cattle pasture, another avocado orchard and by a tree-lined creek. Some trees had been subjected to heavy canopy pruning just prior to the first year's sampling, and insecticide applications were varied and frequent.

Avocados (East Mareeba) – Situated 10 km east of Mareeba, this small orchard contained 100+ large trees of the variety Shepard. One side of the orchard abutted a row of lychee trees while another adjoined a row of jackfruit. This orchard was less than 100 metres from a large organic orchard that contained a variety of fruit types. Some insecticides were applied on a needs basis, but in most other respects management was minimal.

Avocados and macadamias (Mareeba) – This was a mixed orchard belonging to the Burdekin Agricultural College, which contained rows of 20 avocado and 20 macadamia trees, each of mixed varieties. Other crops represented at the site were mangoes, citrus, carambolas, lychees, longans, cashews and a few rarer exotic species. The orchard had minimal management, but endosulfan was applied regularly from mid-December.

Tree selection. At Kairi, Atherton, Malanda and East Mareeba, trees for regular sampling were selected in a semi-random way to provide information on bug dispersion and aggregation within an orchard. Trees were selected on the orchard edges and in more central
positions, and were sampled in groups of three or sampled singly.

Sampling procedures. In 1997/98, 30 trees were sampled each fortnight at each of Kairi, Atherton, Malanda (20 Fuerte and 10 Hass) and East Mareeba. Sampling commenced in early September and continued through to February-March for the avocados and April-May for the macadamias. In 1998/99, 30 trees were sampled at Kairi and East Mareeba, and 20 trees at Atherton and Malanda (15 Fuerte and 5 Hass). At the Burdekin Agricultural College orchard, 10 avocado and 10 macadamia trees were sampled. The sampling frequency was fortnightly, and the period was basically the same as in 1997/98.

In 1997/98, 15 panicles or racemes were examined on each sampled tree. Ten were accessible from the ground and 5 from a ladder (up to 4 m high). The diameters of up to three nuts or fruit were measured with callipers, the number and types of insect damaged and undamaged nuts or fruit recorded, and any insects present, noted. In 1998/99 10 panicles or racemes
(7 low and 3 high) were examined on each sample tree, with the diameters of only one fruit or nut in each sample measured. Insect damage was recorded as in 1997/98. In both seasons up to 15 fallen macadamia nuts from beneath sample trees were cut open to record any insect damage.

Other data recorded. At the end of each season samples of nuts were collected from beneath trees that had shown significant levels of bug activity, to ascertain the degree of residual damage. Nuts were cracked with a leverage (macadamia) cracker and the kernels rated for occurrence of bug damage. Information on the oil content of avocados at maturity was obtained from the co-operating growers. Growers of both macadamias and avocados provided details of all chemical applications associated with each crop.

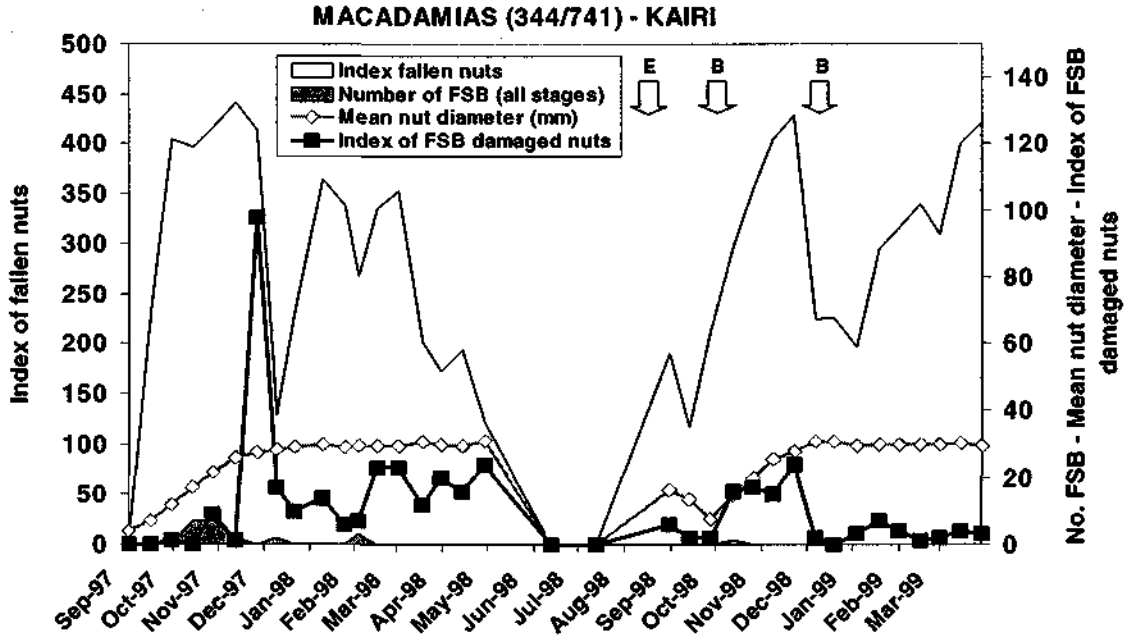
Data handling. All data were entered into a Microsoft Access® database. This permitted easy retrieval and preparation of summaries. The database contained 57,696 records at the completion of sampling.

Results

Macadamias.

Kairi – In the 1997/98 season in the absence of any chemical treatments, the *Sigastus* weevil caused substantial damage to nuts, some of which masked the fruitspotting bug damage and led to an underestimate of bug activity in September/October (Figure 25). However fruitspotting bugs were observed in the crop from early October, indicating that some damage to nuts would have occurred from mid-late September. This concurs with the findings in 1998/99. In both years premature nutfall largely ceased in early-mid December when the nut shells hardened, despite some bugs being observed in the crop until February-March (Figure 25). The number of bug damaged nuts was substantially higher in 1997/98 than in 1998/99, and some bug-damaged nuts occurred continually until crop harvest suggesting differential rates of fall. At harvest, less than 2% of nuts from under trees with heavy bug activity showed bug damage. *A. nitida* was the only species observed at this site over the two seasons.

Figure 25. Fruitspotting bug activity vs crop phenology in macadamias at Kairi during 1997/98 and 1998/99. E = endosulfan applied, B = Bulldock applied.



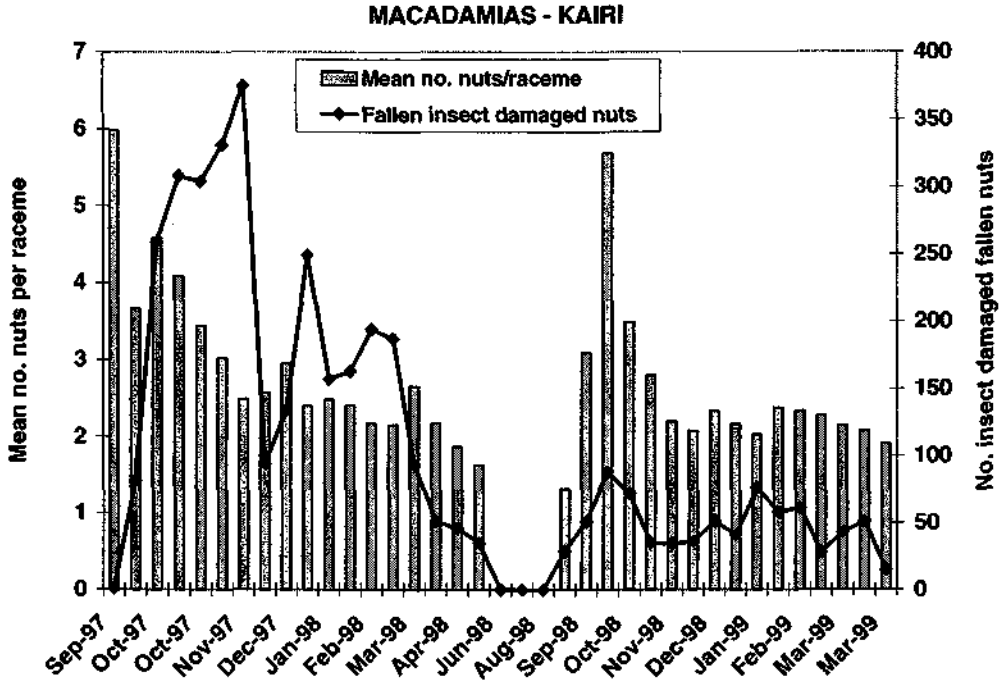


Figure 26. Fallen, damaged nuts vs numbers of nuts per raceme at Kairi over two seasons

Despite the greater numbers of insect damaged nuts falling during the 1997/98 season compared to the following one, there was little difference in the number of nuts remaining on racemes at the end of each season (Figure 26).

The frequency of detection of bugs or bug damage was considerably higher in the Kairi crop in 1997/98 than in 1998/99 when some sprays were applied (Figure 27). Only four trees of the 30 sampled contained bugs or bug damage in both years, while there was no bug activity recorded in 11 trees (37%) at any time. When no insecticides were applied, in all instances when bug damage was detected in a tree in a group of three, other trees within the group also contained damage. When sprays were applied, only 50% of the other trees within a group showed bug damage.

Atherton – There was negligible fruitspotting bug damage in either the 1997/98 or the 1998/99 crops, and only a single bug was observed during the entire sampling period. Despite differences in the mean number of nuts per raceme soon after nut-set in the two seasons, there was little difference in the number of nuts remaining on the trees in the two years when crops approached maturity (Figure 28).

Figure 27. Patterns and frequency of fruitspotting bug activity in the Kairi macadamia crop between mid-October and mid-December for 1997/98 and for 1998/99. The orchard configuration is not exact. Shaded areas represent the trees sampled. NB. The numbers in the squares indicate bug or damage (≥ 2 damaged nuts/tree) detection frequency.

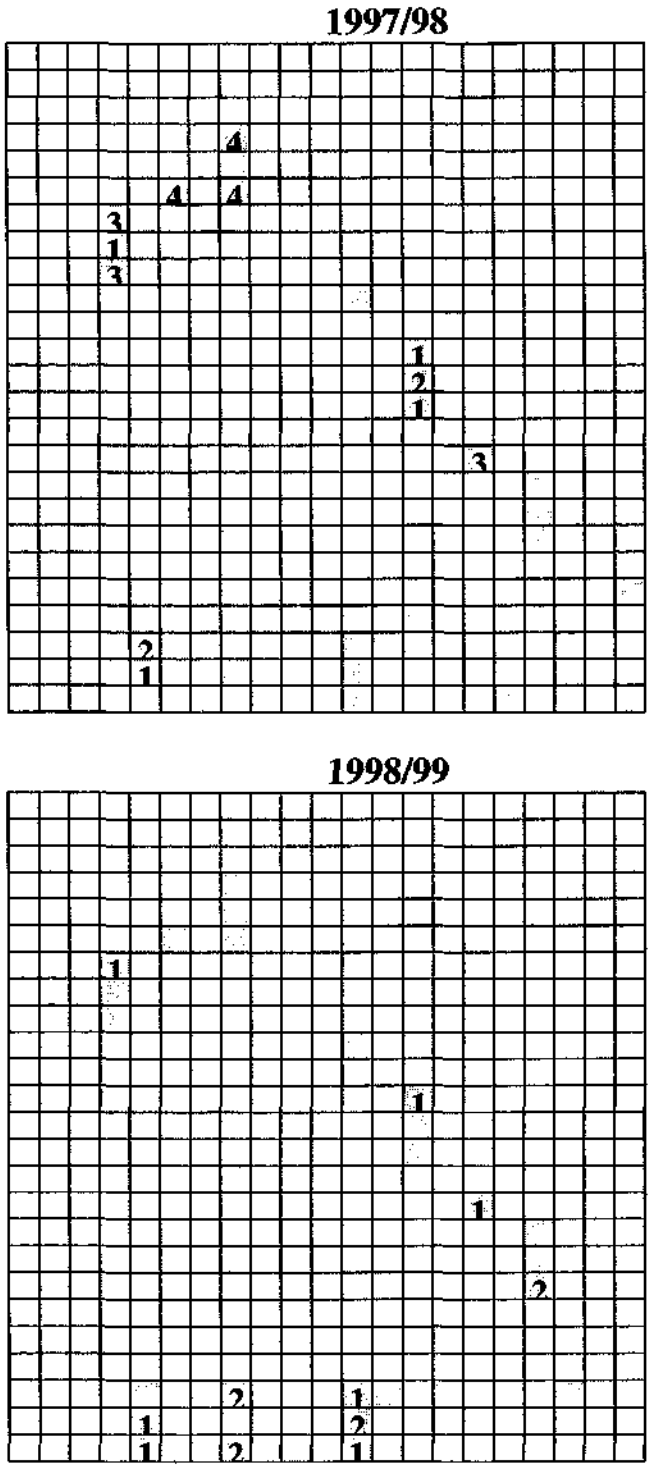
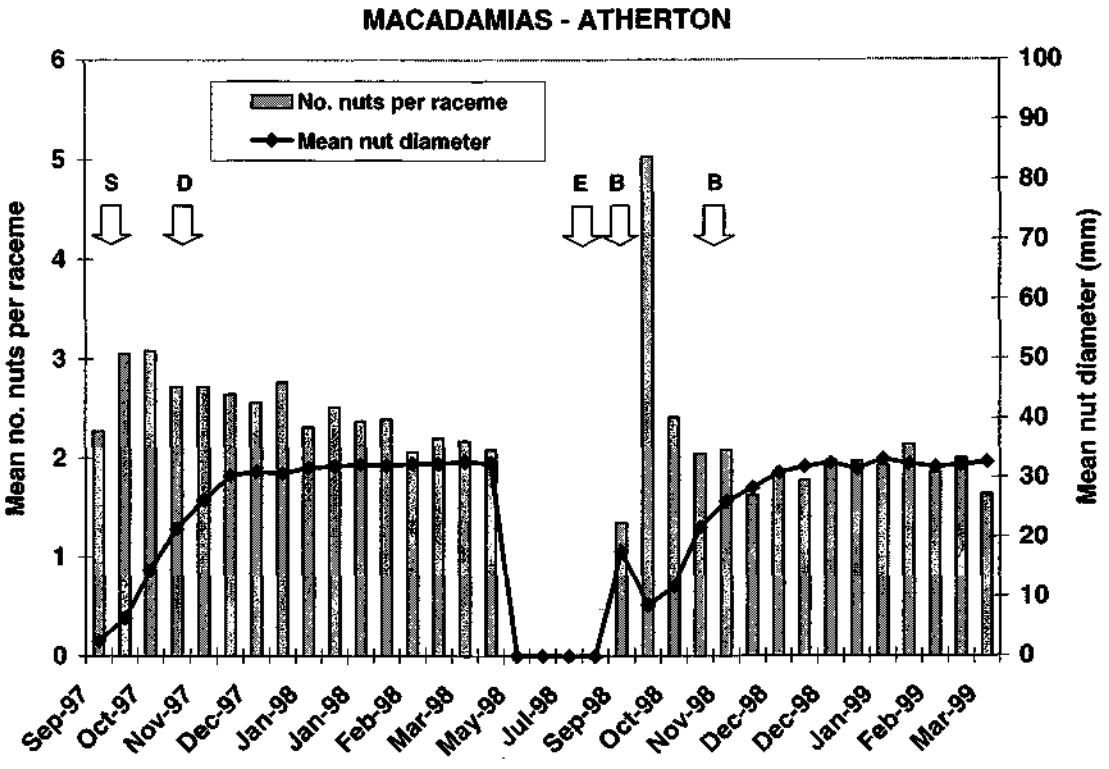


Figure 28. Numbers of nuts remaining per raceme vs nut size at Atherton over 2 seasons. S = Supracide applied, D = Dipterex applied, E = endosulfan applied, B = Bulldock applied.



Mareeba – Fruitspotting bugs, *A. lutescens*, were detected in trees at this site between late September and late November 1998 (Figure 29). Bug-damaged nuts were prevalent during this same period, with a peak in early November. There were few bug-damaged nuts recorded from mid-December, at shell hardening, but some did occur late in the season as the crop approached maturity. Only *A. lutescens* was recorded at this site.

The mean number of nuts per raceme from the two trees with the greatest amount of bug damage were compared against those from the two trees with the least amount of damage through the cropping season. The level of bug activity in a tree during October and November appeared to be of little consequence to the number of nuts per raceme remaining as the crop approached maturity (Figure 30).

Figure 29. Fruitspotting bug activity vs crop phenology in macadamias at Mareeba in 1998/99. E = endosulfan applied.

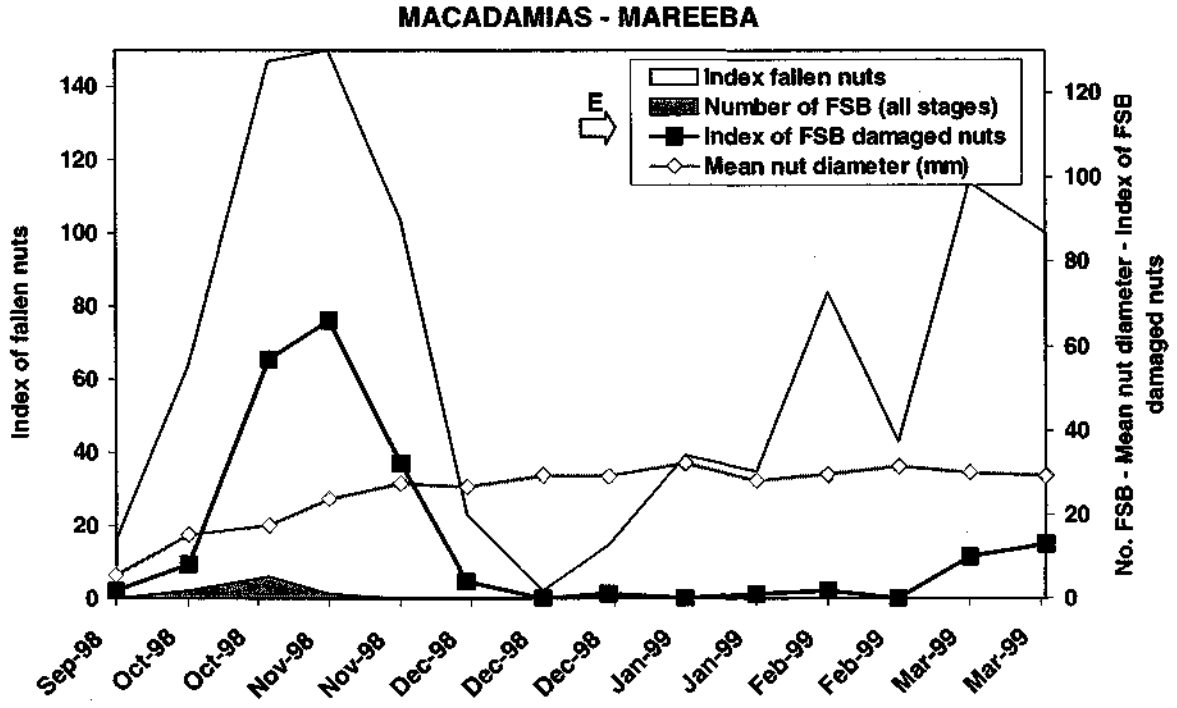
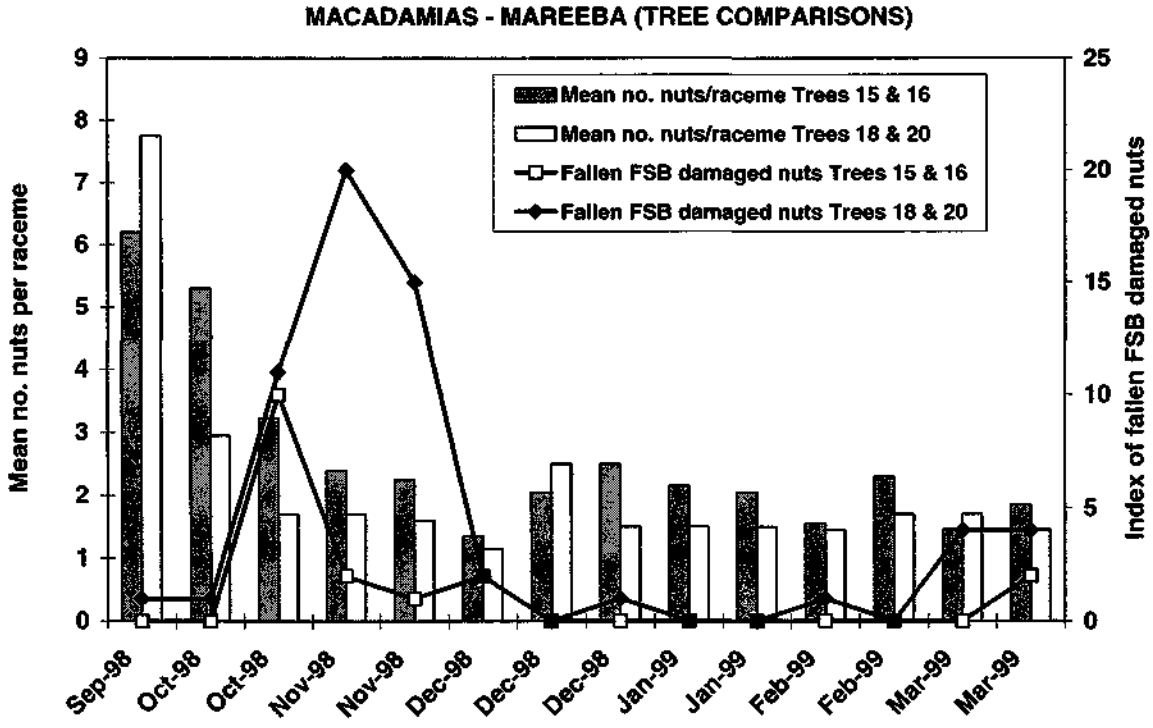


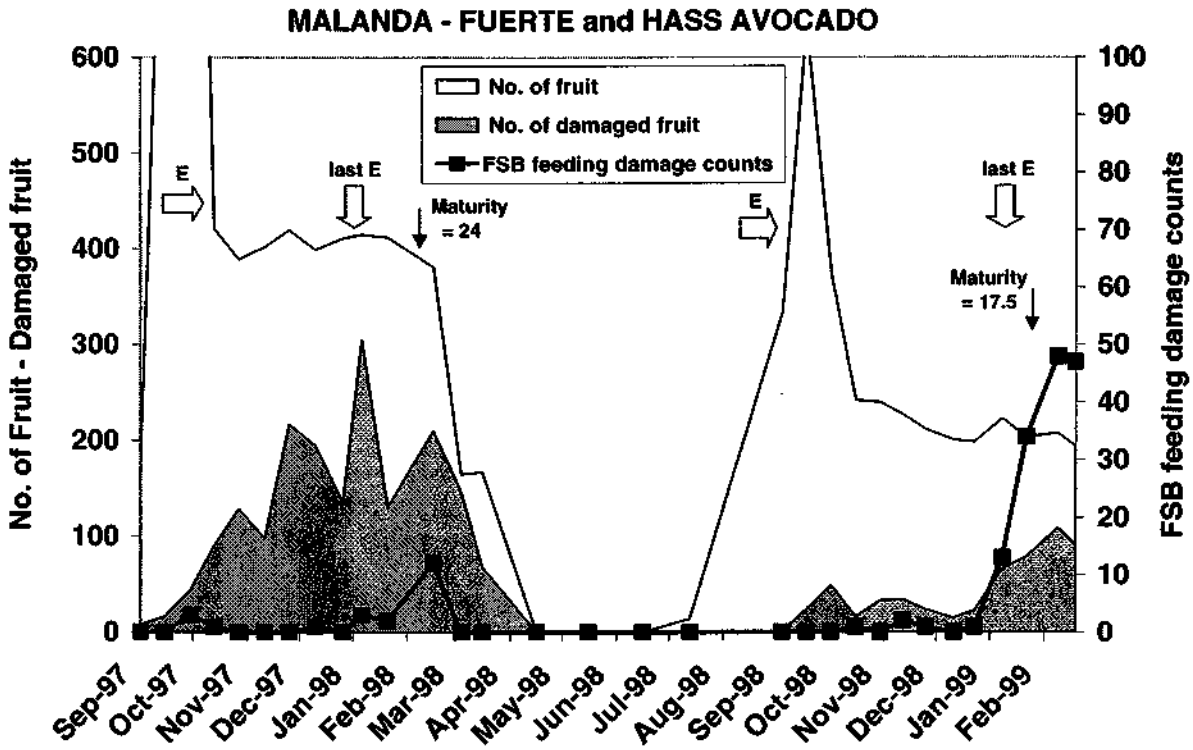
Figure 30. Fallen bug-damaged nuts vs number of nuts per raceme in two sets of trees at Mareeba in 1998/99.



Avocados

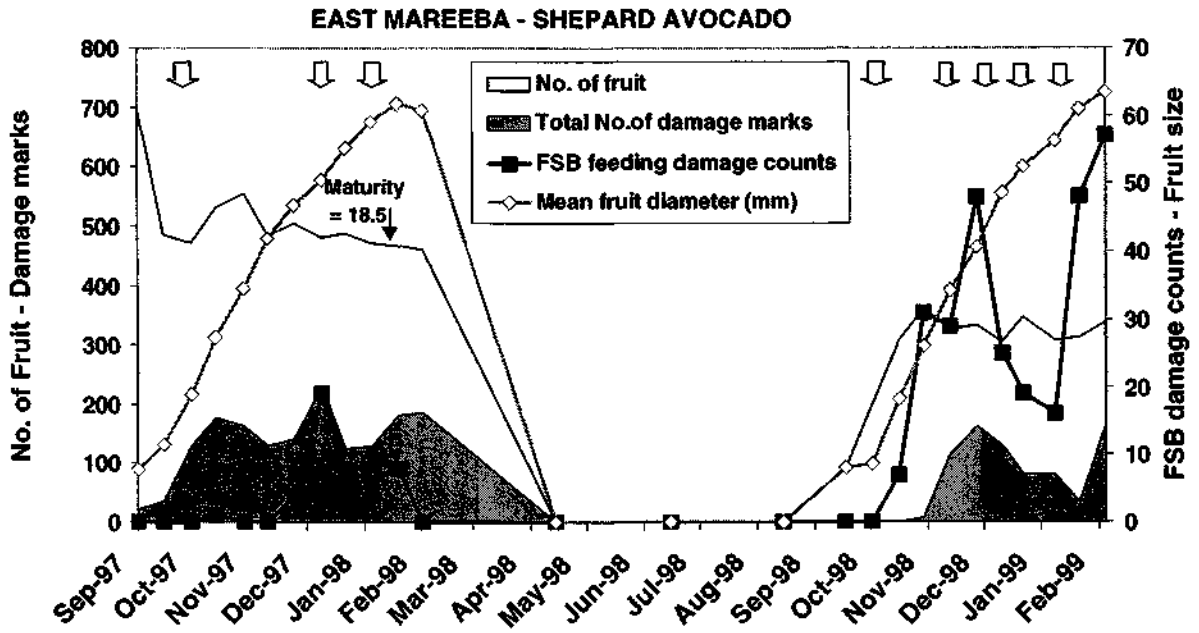
Malanda –Endosulfan and other insecticides were applied regularly at this site throughout both seasons so that bug damage levels were generally low. The higher levels of fruit damage in 1997/98 (Figure 31) were due primarily to *Monolepta* and to a *Taylorilygus* sp. However as fruit approached maturity and after spraying had ceased, bugs did appear to enter and/or survive in the crop, so that in both years Fuerte suffered late bug damage (Figure 31). Most of this damage occurred on one corner of the orchard close to a creek. *A. nitida* was the only spotting bug species observed at this site.

Figure 31. Fruitspotting bug activity in an avocado crop at Malanda during 1997/98 and 1998/99. E = endosulfan applied.



East Mareeba – The 1997/98 and 1998/99 seasons were contrasting at this site, particularly in terms of crop size and the type and level of insect damage incurred. In 1997/98, most of the damage to fruit in September and October was caused by *Helopeltis* sp. Subsequent to this, mainly in late November to mid-December, fruitspotting bug damage was evident but still relatively minor (Figure 32). This damage appeared to occur because no insecticides were applied during this period. In 1998/99, sprays for spotting bug were more frequent than in the previous season, but the incidence of bug damage was considerably higher. From October, *A. lutescens* appeared to move from an adjacent row of lychee trees into the avocados, and the bug damage to fruit continued to increase until December. The regular spraying then seemed to bring the situation under control, but damage commenced again once insecticidal intervention stopped at the end of January (Figure 32).

Figure 32. Fruitspotting bug activity vs crop phenology in avocados at East Mareeba in 1997/98 and 1998/99. The arrows indicate when sprays for spotting bugs were applied.



Mareeba – Adults or nymphs of *A. lutescens* were observed at various times through the entire season. While some bug damage occurred on small fruit during October, most was recorded in February-March as fruit approached maturity (Figure 33). This late damage occurred despite regular endosulfan applications, but did not cause the fruit to fall.

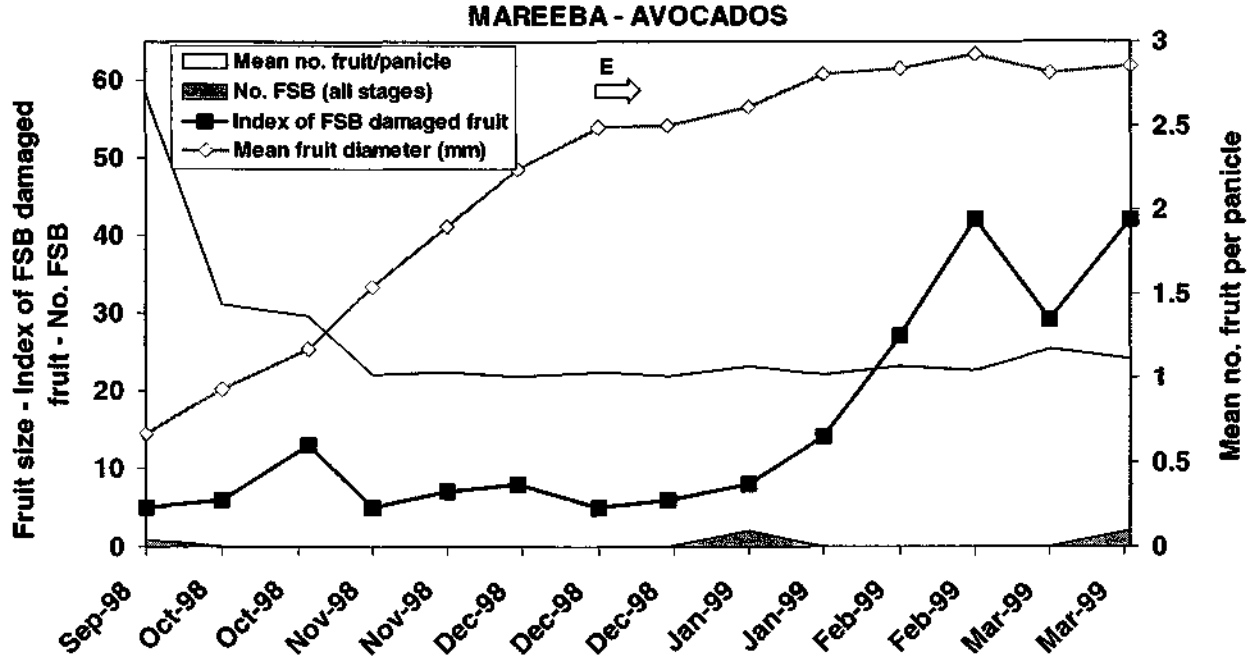


Figure 33. Fruitspotting bug activity vs crop phenology in avocados at Mareeba in 1998/99. E = endosulfan applied.

Discussion

Extensive data have been presented, which allow some comment on the significance of fruitspotting bug activity through the production season of a macadamia or avocado crop. These two crops appear different in terms of when and to what extent fruitspotting bugs impact on them. An opinion will be offered on the significance of this to bug management, including the potential for a reduction in insecticide use.

In macadamias, 2 to 3 sprays between late September and late November, ie. just prior to shell hardening, generally controlled fruitspotting bugs where they were applied to the crops studied. Most spotting bug activity was detected prior to shell hardening, and during the period when the level of natural crop shedding by trees was high. The data suggested that irrespective of the degree of nut set, or the amount of insect damage incurred during this period, the number of nuts remaining per raceme from around shell hardening was about two. Evidence presented elsewhere in this report suggests that most nuts fed on by bugs through the early stages of nut development will fall. If this is in fact the case, then the need to spray for bugs during this period must be questioned. The only application required would coincide with the first treatment for macadamia nutborer, to ensure that resident bugs and their progeny did not cause any residual problems later in the crop. However, there was an indication in the Mareeba data that a few bug-damaged nuts may not have fallen soon after being damaged, but remained on the tree until mature. While this phenomenon appeared very minor, it may still be of sufficient consequence to cause processors problems, and sway a decision on insecticide applications at an earlier stage in crop development. Clearly, additional work needs to be done on the fate of damaged nuts on trees, and varietal differences in this respect.

In avocados, bug damage was recorded in crops throughout the entire season. While some fruit damaged early in the season fell soon after, other fruit continued to hang right through to maturity. This has also been observed in mangoes in South Africa after small fruit were damaged by *Pseudotheraptus wayi*, a species closely related to the fruitspotting bugs (Neethling and Joubert, 1994). In the avocado crops that were monitored in this project it appeared that failure to apply control measures at any time during the season led to rapid bug damage, even at the time fruit had reached maturity. There appear to be few opportunities in avocados to rationalise spray schedules for fruitspotting bugs. Monitoring for bug activity, the identification of specific trees in which to target control, an accumulation of local knowledge of bug activity and the rationalisation of insecticide applications by considering additional pests (eg. leaf rollers, fruitborer, fruit fly) affected by bug sprays appear to be the only ways a grower is able to reduce insecticide use.

In some of the crops examined during this work there were definite edge effects in the intensity of bug damage, but in others the distribution of bugs and damage was more random.
Monitoring bug activity and/or documenting damage history are the only ways to determine whether specific trees are more likely to attract bugs than others, and individual growers need to develop profiles for their orchards based on this information and the proximity and seasonal role of alternate bug hosts.

Finally, this study has indicated that *A. nitida* is the predominant spotting bug active in crops on the higher parts of the Atherton Tableland of north Queensland. It was previously considered a species of little consequence to growers in the northern parts of the state. This finding will be important if pheromones are ever developed to a stage where they can be used as monitoring tools.

14. Fruit phenology in relation to fruitspotting bug susceptibility

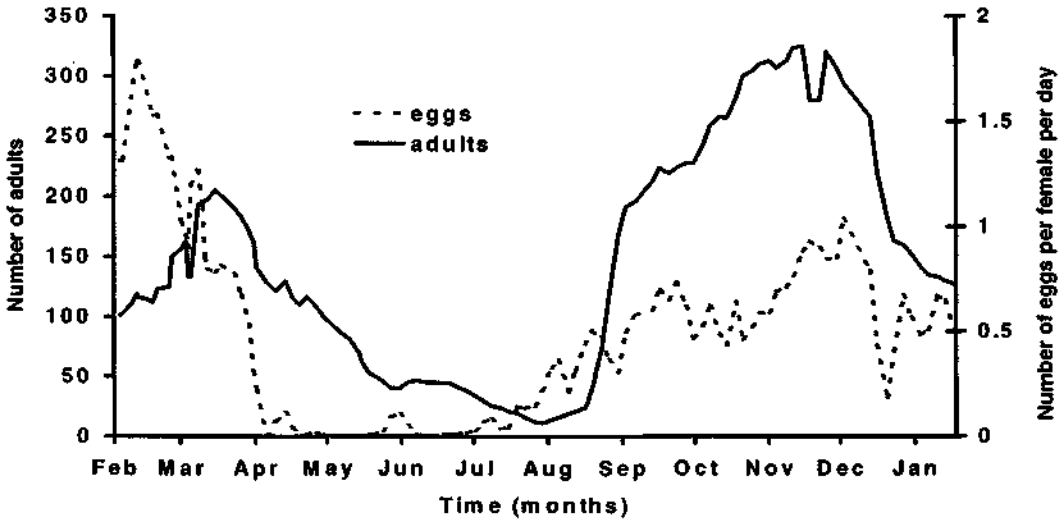
Introduction

Fruitspotting bugs generally prefer to feed on immature green fruit (Waite and Huwer, 1998). This applies across a wide range of fruit hosts. In some crops such as custard apples, macadamias, lychees and mangoes, the bugs may feed on the flowers. Such damage is usually inconsequential, except in custard apples. *A. lutescens* has a propensity to feed on and destroy the terminal growth of several crop plants, most notably mangoes and papaws, but will also damage macadamia and cassava shoots.

Interest in the relationship of fruit phenology to fruitspotting bug attack and damage relates to three main facets of the fruiting cycle. Firstly, most of the tree crops that are targeted by the bugs produce hundreds of thousands, perhaps millions of flowers and subsequently set many more fruit than could ever develop to maturity. Losses caused by any factor at this time are tolerable, provided final fruit numbers do not fall below the threshold limit that determines an adequate economic yield. Secondly, having set more fruit than can be matured, fruit trees reach a stage in the season when supply and demand of carbohydrates becomes critical, and much of the fruit is shed in order to protect the viability of the final crop. Insect damage to fruit that is predestined to be shed, is therefore also of no consequence. Thirdly, because fruitspotting bugs tend to concentrate their attention on immature fruit, there is a time during the season when the danger posed by them recedes as the fruit matures, and spraying can cease. A good understanding of the relationship of the bugs with all of these phenological phases would help to define the period of real threat to final yield, and to develop better strategies for protection of the crop.

Biological switch-off by the bugs in preparation for over-wintering could possibly be used to predict when they might cease feeding on crop hosts and retreat to their over-wintering hosts. Laboratory data concerning the production of eggs by females indicate that reproduction and general fruitspotting bug activity start to slow at the end of March and by the middle of April, activity has dropped off significantly (Figure 34). This period coincides with shortening day-length as well as the onset of cooler conditions, both of which may have some effect on the bugs' behaviour. Either of these factors or a combination of both may trigger the onset of the bugs' winter mode of 'just hanging around', without feeding too much. When the days lengthen and temperatures increase in spring, activity picks up to coincide with flowering and the setting of fruit (Figure 34), especially on the bugs' many commercial fruit hosts.

Figure 34: Seasonal reproductive trends for fruitspotting bugs, *Amblypelta nitida*, recorded under ambient conditions at Maroochy Research Station between February 1998 and January 1999.



The following studies were aimed at determining how selected fruits respond to fruitspotting bug damage, what the symptoms are at each stage of fruit development and how long it takes for them to be manifest, either as lesions on the fruit of in the initiation of abscission. In avocados in particular, the fate of damaged fruit was of interest since at present monitoring for the bugs' presence can only be carried out by detecting damaged fruit on the tree. For monitoring purposes we need to know how soon after a fruitspotting bug feeds on the fruit can the resulting damage be seen, and also what proportion of the fruit falls from the tree as a result of bug attack. The latter will determine to some extent how much real damage is evident to anyone monitoring, and it may also influence the way in which growers perceive the problem. Such perceptions are often only gained at harvest when much of the damaged fruit may have fallen and so is not accounted for in the final damage tally.

14.1 In-field cage studies on avocado, macadamia and custard apple -1998/99

Introduction

Studies were conducted in macadamias and custard apples at Maroochy Research Station and avocados on a neighbouring commercial property, and were designed to evaluate how avocado, macadamia and custard apples respond to fruitspotting bug damage. In other words, what happens to the fruit and nuts after a bug has fed on them? Does the response change as the fruit and nuts grow progressively larger?

Methods

In avocado the experiment was performed at monthly intervals between October 1998 and February 1999 inclusive. In macadamia the experiment was also repeated at monthly intervals, except for February 1999. In February, the shell was hard and dark brown in

colour and since results obtained in January revealed that damage did not induce nut drop at that time, it was decided that kernel damage was unlikely to have occurred in February. In custard apples the experiment was performed in February only. This was possible because of the prolonged flowering of this crop, which produces a range of fruit sizes at any time from early to mid-season. Fruit were selected on the basis of diameter categories: small (20-30mm), medium (40-50mm) or large (60-70mm) (Table 23). The experiment was conducted on two avocado varieties, Hass and Fuerte, and two macadamia cultivars, 344 and 741. Only African Pride was used in custard apple experiment.

The experiment consisted of a treatment and a control, with treated fruit/nuts (treatment) being caged with a single bug for 24 hours. Fruit/nuts in the control treatment were protected by a cage to prevent wild bugs from gaining access to the fruit/nuts, but no bugs were added. Cages consisted of a mesh bag 400mm x 200mm with mesh diameter of approximately 1mm and with a drawstring at one end to fix the cage to the branch (Plate 10). Wherever possible the cages were tied onto the branch in such a way that in addition to fruit/nuts they contained at least one leaf on which the bugs could rest and shelter. All cages and bugs were removed after 24 hours and the fruit/nuts were tagged and numbered for identification. At the commencement of each experiment, 40 treatment and 40 control branches were caged and tagged, except in October when only 20 branches were caged and tagged in both the avocado and macadamia experiments. Branches were located on all aspects of the tree and were in the lower part of the canopy at 1-2m. Wherever possible an equal number of treatments and controls was selected on the same trees. The number of trees used each month varied, depending on how many fruit/nuts were available. Branches were excluded from the treatment if the bug died while it was in the cage, or if the fruit/nut fell or the branch died as a result of handling.

There were subtle differences between the crops with regard to the experimental method used. One of the main differences was a varying number of fruit/nuts caged and/or tagged at the beginning of each experimental month. For example in October, avocado and macadamia racemes were caged and/or tagged irrespective of how many fruit or nuts they contained whereas between November and February, branches were selected only if they contained a certain number of fruit or nuts. In the custard apple experiment only a single fruit was caged and/or tagged. The frequency of observations also varied between crops. In avocado and custard apple, observations were made at weekly intervals for the first four weeks with a final observation made on the eighth week i.e. two months after the first observation. In macadamia, observations were made every second day for the first two weeks only.

Plate 10: The cage used to contain fruitspotting bugs on avocado, custard apple and macadamia branches for 24 hours.

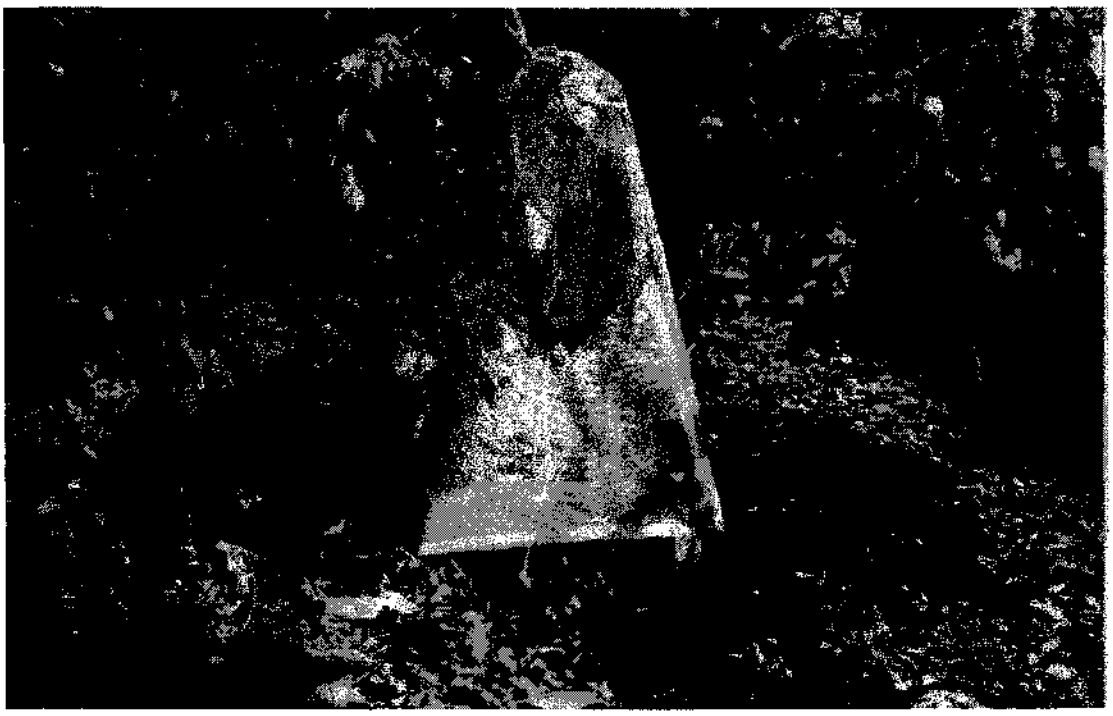


Table 23: Diameter (median and range) of small, medium and large avocado, custard apple and macadamia selected for analysis, the corresponding month is given.

Tree	Variety / Cultivar	Fruit Diameter (mm) (Median and Range)		
		Small	Medium	Large
Avocado	Hass	16 (10 – 22)	41 (31 – 49)	58 (50 – 69)
	Fuerte	18 (13 – 25)	45 (36 – 56)	65 (49 – 76)
		October	**December**	**February**
Custard Apple	African Pride	26 (20 – 30)	46 (40 – 50)	66 (60 – 70)
		January	**January**	**January**
Macadamia	344	4 (2 – 14)	23 (17 – 32)	30 (24 – 43)
	741	4 (3 – 6)	22 (13 – 25)	30 (21 – 27)
		October	**November**	**December**

In the October avocado and macadamia experiments an equal number of male and female fruitspotting bugs, *Amblypelta nitida*, was used as well as an equal number of male and female banana-spotting bugs, *Amblypelta lutescens*. Other experiments subsequently revealed that there was no significant difference in damage potential with regard to species or sex, so all remaining experiments were performed using a random selection of

bugs from the laboratory culture, except for the custard apple experiments in which only *A. lutescens* was used

Results and discussion

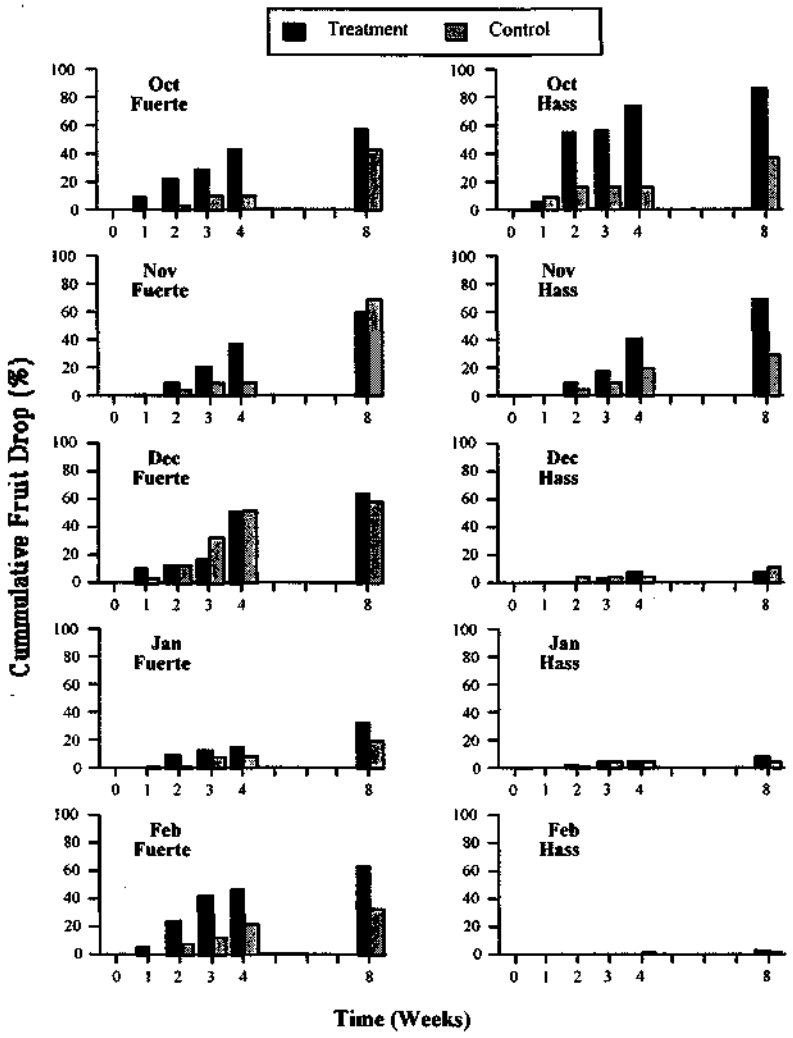
Avocado

In the avocado experiments, Fuerte and Hass showed completely different responses to fruitspotting bug damage. Although the recognition of damage was relatively easy in Fuerte, it was often difficult if not impossible to see in Hass, particularly as the fruit size increased. We also discovered that damage did not always lead to the production of the white exudate often associated with fresh fruitspotting bug damage to avocado fruit. Only 20-25% of the damaged fruit produced the exudate. It is therefore considered to be an unreliable symptom and probably should not be used as a monitoring tool.

In Fuerte, fruit damaged by fruitspotting bugs dropped continuously throughout the experimental period (Figure 35). For fruit caged with bugs in October, November and December approximately 60% of the damaged fruit had dropped by week eight. The control fruit suffered a similar fate suggesting that the trees did not differentiate between damaged and non-damaged fruit while natural thinning was occurring. In January, fruit drop was considerably lower when approximately 20% of both the treated and control fruit had dropped by the end of week eight. In February, fruit loss was substantially higher with approximately 60% of the damaged fruit dropping by week eight compared with approximately 30% in the control. The high loss rate at this time could probably be attributed to the increased incidence of anthracnose that developed in the fruitspotting bug lesions and which was encouraged by the wetter conditions.

Hass trees responded differently in that natural fruit drop was relatively low throughout the entire experimental period (Figure 35, see control fruit drop). Interestingly, fruit damaged by fruitspotting bugs dropped readily in October and November but it was retained on the tree in December, January and February. Much of the damage sustained in January and February was undetectable and the extent of the damage could only be determined by peeling the fruit to reveal the water-soaked marks in the flesh beneath. Even growers who thought they knew how and what to look for with respect to fruitspotting bug damage were surprised when shown how much actual damage was present, but that couldn't be seen. How much of this damaged fruit finds its way into packs of first grade fruit?

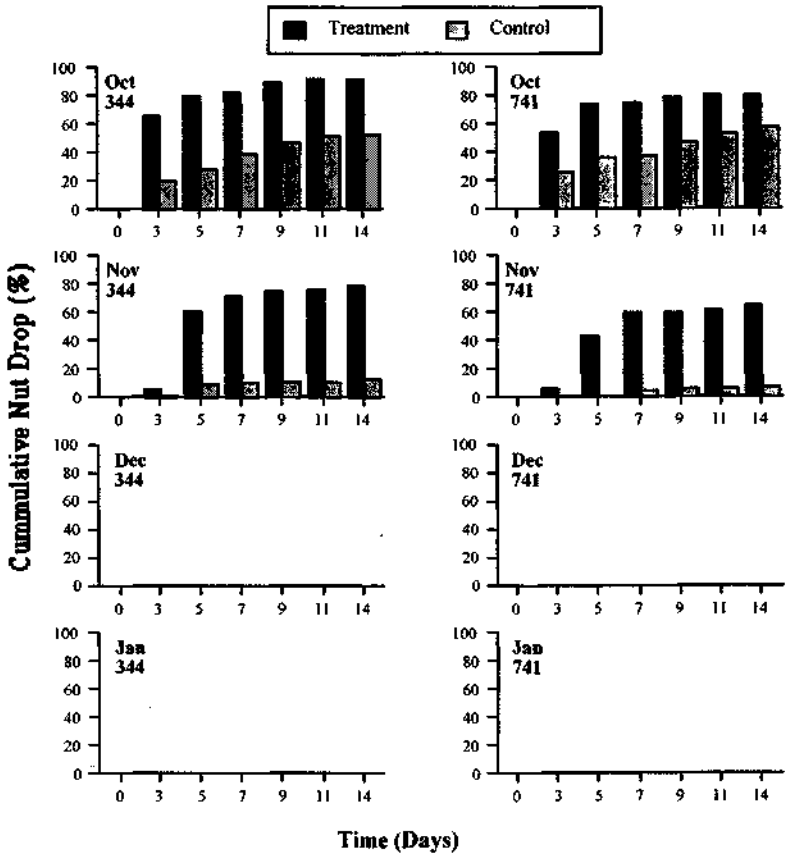
Figure 35: Cumulative fruit drop in avocados expressed as a percentage for Fuerte and Hass. Avocado fruit were either caged with bugs (Treatment, n = 40) or without bugs (Control, n = 40). The experiment was repeated in October 1998, November 1998, December 1998, January 1999 and February 1999.



Macadamia

Both macadamia cultivars (344 and 741) responded in much the same way when exposed to fruitspotting bugs (Figure 36). Damaged macadamia nuts dropped considerably quicker than damaged avocado fruit. While avocado fruit may take several weeks to abort, most damaged nuts fell within a week. None of the nuts damaged in December and November aborted, and the trees retained these to maturity. This has important implications for the final harvest quality and also for pest scouts who probably need to make a greater effort to sample nuts from the tree to detect fruitspotting bug damage at this time of the year.

Figure 36: Cumulative nut drop expressed as a percentage for 344 and 741. Macadamia nuts were either caged with bugs (Treatment, n = 40) or without bugs (Control, n = 40). The experiment was repeated in October 1998, November 1998, December 1998 and January 1999.



14.2.1 Identifying fruitspotting bug damage on avocado

Although most growers are able to recognise fruitspotting bug damage on thin-skinned varieties such as Fuerte, they have a problem with thick-skinned varieties like Hass. The following data show that although Fuerte is an early maturing variety, the early season phenology of the two cultivars is similar. Hass fruit at a similar stage of development is present in the field along with that of Fuerte at the beginning of the season and both are available as a food source for fruitspotting bugs in October. Both varieties are susceptible with the only real difference between them being the difficulty in recognising fruitspotting bug damage in Hass.

Throughout the 1998/99 caging experiment the number of fruitspotting bug feeding sites (stings) on the fruit was assessed when the cages were removed. It is important to note that the assessments were made and the counts recorded in the field while the fruit were still hanging on the tree. This made it especially difficult to detect the stings, as the fruit was often shaded within the canopy. However, such conditions would also prevail if a grower or a consultant was to attempt to assess fruitspotting bug damage in the field without using a destructive sampling technique.
In Fuerte the caged fruitspotting bugs fed an average of five times during each 24-hour period, irrespective of fruit size (Table 23). Fruitspotting bugs caged on Hass appeared to

find the fruit less appealing, especially as the fruit increased in size. Although an average of four stings was recorded on the small fruit, it was difficult to find a single sting on the large fruit (Table 24).

Table 24: Number of stings recorded on Fuerte and Hass after they were exposed to one fruitspotting bug for 24 hours (n = 40 at each time interval). The experiment was repeated in October, December and February, when the fruit were categorised as small, medium and large.

Fruit category	Month	Number of fruitspotting bug stings (Median and Range)	
		Fuerte	Hass
Small	October	5 (0 - 14)	4 (0 - 12)
Medium	December	5 (0 - 13)	2 (0 - 6)
Large	February	5 (0 - 12)	1 (0 - 8)

On this evidence it might be assumed that Hass is less susceptible to fruitspotting bug damage than is Fuerte. This is not necessarily so! After the February caging experiment all of the fruitspotting bugs were removed and caged on another series of fruit. Even though as laboratory-reared bugs they had already been 'conditioned' by feeding them on avocados in the laboratory prior to the first caging, the extra exposure to 'live' fruit on the tree apparently initiated normal feeding on the new fruit. When the fruitspotting bugs were removed after 24 hours the fruit were picked immediately. The number of stings was counted with the skin intact and also after it had been removed with a potato peeler (Table 25). On Fuerte fresh damage was relatively easy to identify, with the feeding sites visible as darker bruised areas, often referred to as 'water soaked', just below the skin. At this stage, the cracking sequence had not commenced. A similar number of stings was recorded before and after peeling on Fuerte (Table 25). In complete contrast, identifying damage on Hass fruit externally was virtually impossible - remembering that this was late-season damage. Prior to peeling it was extremely difficult to find any evidence of damage because of the thickness of the skin (Figure 37), whereas after peeling we found an average of six stings per fruit (Table 25). In this non-choice caged situation fruitspotting bugs fed at the same rate on Fuerte and Hass fruit. There was no significant difference between the two in terms of the number of stings recorded after 24 hours, and the only difference between the two varieties was our ability to recognise the damage.

Table 25: Number of stings recorded after Fuerte and Hass fruit were exposed to a single fruitspotting bug for 24 hours. Damage was assessed before and after peeling the fruit (n = 26 Fuerte and Hass fruit).

	Number of fruitspotting bug stings (Median and Range)	
	Fuerte	Hass
Before Peeling	5 (0 - 7)	0 (0 - 8)
After Peeling	6 (1 - 12)	6 (1 - 17)

Figure 37: Invisible fruitspotting bug sting on Hass revealed only after removal of the skin

Hass fruit before peeling

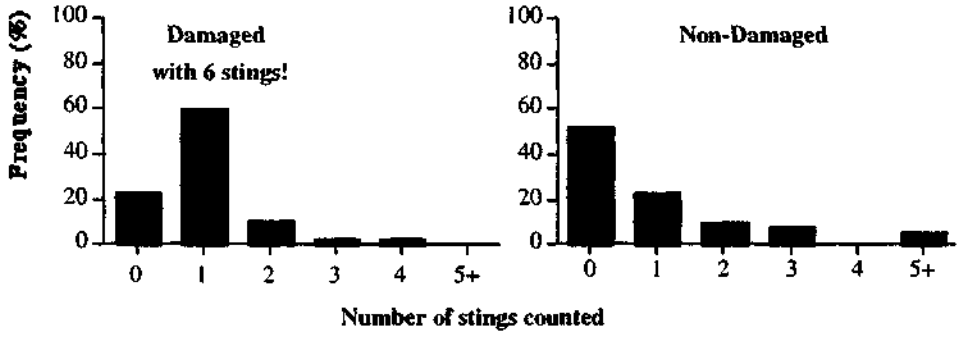
The same Hass fruit after peeling

- **In the field, growers may easily miss the damage. Therefore professional consultants will be required to ensure monitoring is done properly.**
- **In the pack-house as the fruit rolls over the line with dozens of other fruit, it is unlikely that fruitspotting bug damage will be recognised.**

Growers attending the Sunshine Coast Avocado Growers Association field day at Glasshouse on 9 June 1999 were asked to assess 12 Hass avocado fruit for the presence or absence of fruitspotting bug damage. The fruit used in the assessment was sourced from the February cage trial. There were seven treatment (damaged) and five control (not damaged) fruit. The individual fruit presented separately and were mixed randomly and numbered from 1 to 12 for identification. The growers were asked to record whether or not each fruit was damaged and if so, how many stings were present. The fruit were then peeled and the actual number of stings recorded. Figure 38 presents the data generated for just two of the fruit, only one of which was damaged.

The data clearly demonstrate how difficult it is to identify fruitspotting bug damage on Hass fruit. The damaged fruit featured above had actually been stung six times but not one person recognised all six stings and 24% of the growers could not see any damage at all! Of those who said the fruit was damaged, 61% found only one of the six stings. Although we expected growers to have a problem finding all of the stings, we didn't expect them to see damage that wasn't there. 48% of the growers 'saw' one or more stings on the non-damaged fruit. This is of some concern if growers relied on their ability to find fresh damage and make spray decisions based on what they see. Perhaps these revelations explain why damaged fruit is still turning up in the market place?

Figure 38: Frequency distribution showing the number of stings growers could see on a damaged and a non-damaged fruit (n = 39 growers).



14.2.2 Avocado packhouse experiment

From a marketing point of view it could be argued that it doesn't really matter if growers and pickers are unable to correctly identify fruitspotting bug damage, so long as those who process and pack the fruit have the expertise to do so. On 21 June 1999, eight staff from the Natures Fruit Company packing house in Nambour were asked to assess 20 Hass avocado fruit for the presence of fruitspotting bug damage. The fruit used in the experiment came from the February caging trial. Ten damaged and ten control (not damaged) fruit were provided. The fruit were mixed randomly and numbered from 1 to 20 for identification. The staff were asked to examine the fruit (they were able to pick it up and turn it around to get a good look) and to record whether or not they considered a fruit was damaged. If a fruit was considered to be damaged, they were to nominate the number of stings they could see. The fruit were then peeled and the actual number of stings was recorded. The data show that those who process the fruit also have a problem identifying fruitspotting bug damage on Hass fruit (Table 26), even when it is stationary and not tumbling along the packing line!

Table 26: Number of fruitspotting bug stings recorded by packers at Natures Fruit Company, Nambour. The number of stings represents the total number of stings found by each packer on all 10 damaged Hass fruit. The number of stings recorded by each individual has been compared with the total number of stings to give a percentage of the actual number of stings detected.

Packer	S	C	H	Y	P	K	M	A
Number of stings	18	10	18	9	34	24	13	33
% of actual stings detected	27.7	15.4	27.7	13.8	52.3	36.9	20.0	50.8

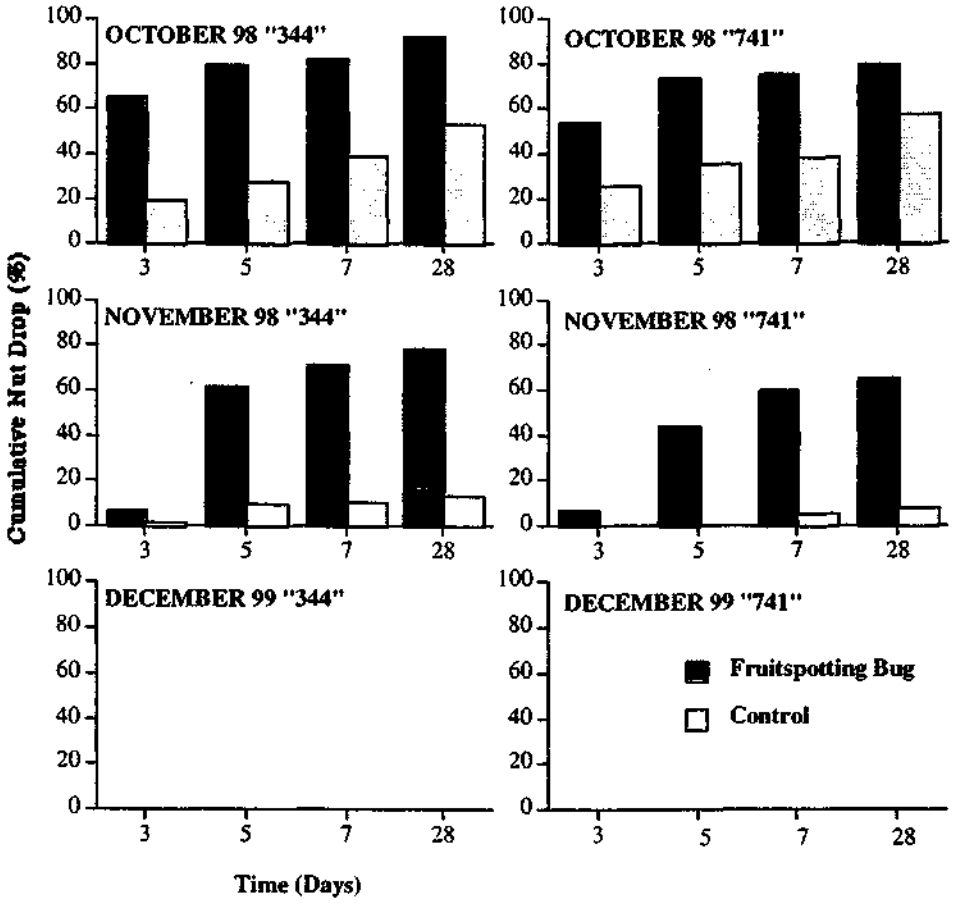
The total number of stings detected by the staff ranged from 9 to 34 when there was in fact, a total of 65 stings on the ten damaged fruit (Table 26). This means that most staff did not recognise at least 50% of the fruitspotting bug stings. If there are more than two or three stings on a fruit, there is a reasonable chance that at least one of those will be visible. However, if there is an allowance in the pack for one or two fruitspotting bug lesions, then fruit with many more stings may very easily be passed and there is a good chance that some damaged fruit will be packed as first grade fruit. Research is required to

determine the effect this damage has on the final fruit quality as it progresses through the market chain and ripens. Preliminary trials revealed that fruit damaged by fruitspotting bug developed more anthracnose lesions than the control fruit, especially in Fuerte.

14.3.1 Macadamia - fruitspotting bug damage and its impact on nut drop

Macadamia nuts of cultivars 344 and 741 responded in much the same way when exposed to fruitspotting bugs for 24 hours. Nuts damaged in October and November dropped relatively quickly compared to damaged avocados. The majority of damaged macadamia nuts aborted within the first week and not over several weeks (Figure 39). Approximately 65% of the damaged nuts aborted within the first three days when nuts were exposed to fruitspotting bugs in October. This compared with 20% in the control. The October 1998 experiment clearly showed that natural nut drop accounts for a large portion of the aborted nuts (Figure 39, see control fruit drop). Four weeks after the experiment had begun just over 50% of the control nuts had aborted whereas 90% of the nuts caged with bugs, had dropped.

Figure 39: Cumulative macadamia nut drop expressed as a percentage for "344" and "741" after exposure to fruitspotting bugs for 24 hours at different times of the year. Fruit were either caged with fruitspotting bugs or without (Control)



Nuts exposed to caged bugs and damaged in November took a few extra days to respond to the damage with the majority taking five days to drop (Figure 39). In October and November the nuts were green and soft and easy to cut in half. By mid-December the

shell had started to harden and we were unable to cut the nuts in half. None of the nuts exposed to fruitspotting bugs in December aborted. They were all retained on the tree until maturity. The nuts used in the December trial were harvested and assessed for damage. None of the nuts had any visible sign of fruitspotting bug damage on the shell or the kernel, and there was no difference between the treatment and control nuts with regard to oil content, weight or taste.

14.3.2 Bug damage to macadamia - fruitspotting bug versus green vegetable bug

Introduction

In this section the term 'bug' refers to both fruitspotting bugs and green vegetable bugs. As a follow up to the trials carried out during the 1998/99 season we set out to clarify the confusion that currently exists within the macadamia industry concerning the type of damage and symptoms produced by each of the pest bugs. We wanted to determine exactly what happens to a nut after a fruitspotting bug or a green vegetable bug has fed on it. Does the nut response change as it develops? When does damage actually affect the shell and the kernel? Does shell damage relate to kernel damage? Do the nuts reach a certain stage of development and then become 'resistant' to bug damage? If they do, perhaps the industry can cease spraying for fruitspotting bugs when the nuts reach a certain stage of development. Can consultants really tell the difference between the two bugs in terms of the damage they see when they are monitoring fallen nuts on the ground? If not, what are the practical implications?

Methods

The same methods and materials that were used during the 1998/99 feeding experiments were used for this trial, which was conducted in a commercial orchard at Palmwoods on the Sunshine Coast. All bugs were caged on racemes of cv. 344 that each carried two nuts. Nut fall was recorded 3, 5, 7 and 28 days after the cages and bugs were removed. Comparisons were made of the effects of fruitspotting bugs, green vegetable bugs with the non-treated control. In October, 40 racemes were used for each bug species and the control. In the November and December experiments, variable numbers of racemes ranging from 57 to 80, were used for each bug species and the control. Throughout the trial, nut size was recorded as an indicator of nut development (Table 27).

Table 27: Diameter (median and range) of cv 344 macadamia nuts used in October, November and December 1999 caging experiments (n=100).

Month	Fruit diameter (mm) (Median and Range)
October 1999	9 (4 - 14)
November 1999	23 (13 -32)
December 1999	29 (20 -33)

Green vegetable bugs were sourced from a culture maintained at Kingaroy QDPI Research Station and from a Pecan Orchard at Moore in southern Queensland. These

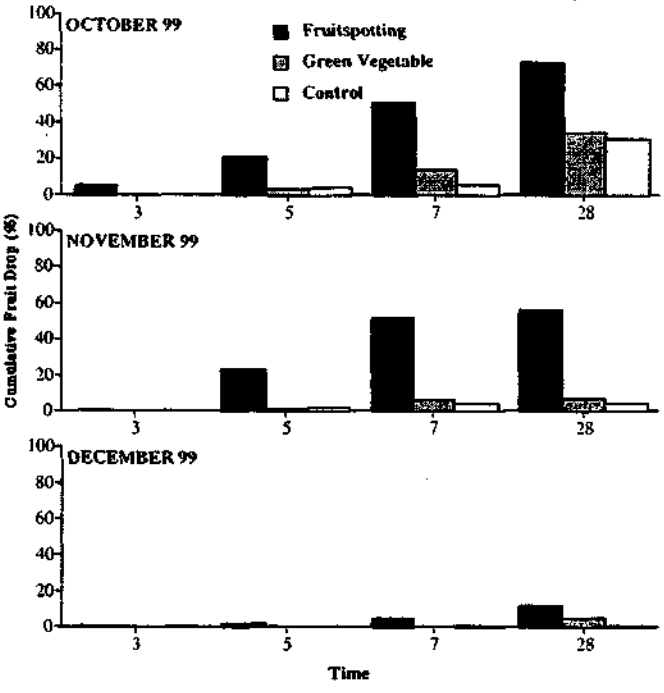
individuals were used to establish a green vegetable bug culture at Maroochy Research Station, which was maintained between October and December 1999 using the same method developed for the fruitspotting bugs.

Results and discussion

Nuts damaged by fruitspotting bugs in October and November dropped within the first week (Figure 40). The experiment performed in October again clearly shows that natural nut drop accounted for a significant proportion of the aborted nuts after 28 days (Figure 40), see control fruit drop). Nuts exposed to green vegetable bugs in October did not drop but were retained on the tree until harvest (Figure 41). In October there was no difference in nut drop between the green vegetable bug treatment and the control. Four weeks after the bugs had been removed approximately 30% of the nuts had dropped in these treatments compared with over 70% in the fruitspotting bug treatment (Figure 40). The result was similar for the November caging, with fruitspotting bugs causing approximately 60% of the caged nuts to abort. Green vegetable bugs again had little impact on nut drop at this time. In November there was no difference between the green vegetable bug treatment and the control. There was no significant difference in the level of nut drop caused by the December caging of fruitspotting bugs when most of the nuts were retained on the tree, and that recorded in the green vegetable bug treatment and the control (Figures 40 & 41). Kernel maturity in the nuts retained was slightly lower than that recorded for the green vegetable bug and control kernel.

To make sure the bugs were feeding on the nuts, a series of observations was made at 3, 6 and 24 hours after they were caged on the nuts in December. At these three time intervals 70% of the fruitspotting bugs were found to be feeding on the nuts and 5% were feeding on the stem. Green vegetable bugs on the other hand, did not necessarily favour the nuts as a food source with only 50% found feeding on the nuts and 41% feeding on the stem.

Figure 40: Cumulative macadamia nut drop for the first 4 weeks expressed as a percentage for cv 344 when exposed to fruitspotting bugs and green vegetable bugs at different times of the year. Fruit were either caged with bugs (fruitspotting bugs or green vegetable bugs) or without bugs (Control).



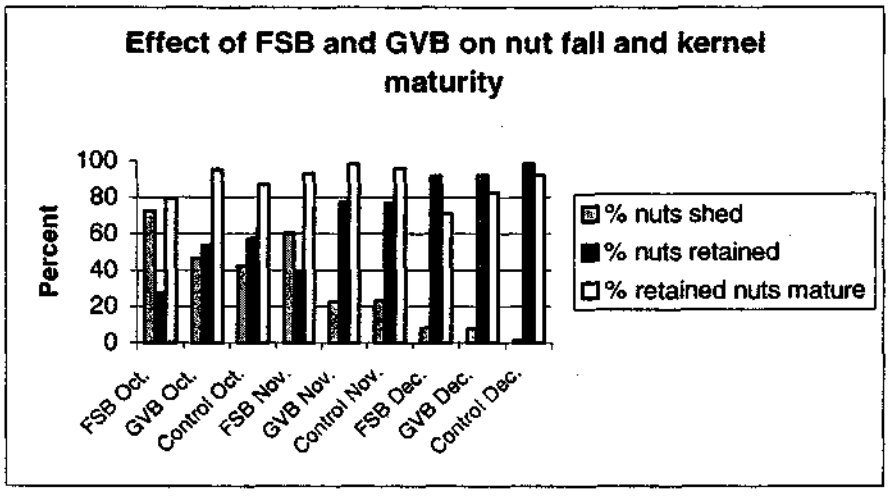


Figure 41: Final nut drop and kernel maturity at harvest for cage experiment with FSB and GVB

14.3.3 Fruitspotting bug damage and its effect on macadamia yield

This experiment set out to determine if a macadamia tree is able to compensate for the loss of nuts early in the season before and during the natural nut drop period. Research conducted in far north Queensland during the 1997/98 and 1998/99 seasons revealed that fruitspotting bug activity in October and November did not appear to influence the average number of nuts remaining per raceme at maturity. It suggested however, that although insecticide applications might not improve tree yield, nut quality might be improved.

Methods

Fruitspotting bug damage levels were monitored on a weekly basis by a commercial consultant in three blocks of macadamias of the cv 344 at Palmwoods during the 1999/2000 season. When fruitspotting bug infestations reached commercial action thresholds determined by the number of damaged fallen nuts, they were sprayed with either endosulfan or β-cyfluthrin except for Block B from which the early endosulfan spray was withheld (Table 28). This provided the opportunity to assess the value of and the necessity for, early fruitspotting bug control. All trees in the orchard were classified according to size and datum trees assigned randomly with reference to these size categories.

Table 28: Insecticide sprays applied to macadamia blocks at Palmwoods

Date	Block A	Block B	Block C
29-9-99	endosulfan	no spray	endosulfan
19-10-99	β-cyfluthrin	β-cyfluthrin	β-cyfluthrin
08-11-99	β-cyfluthrin	β-cyfluthrin	β-cyfluthrin

Assessment of the trial was carried out over three harvests conducted on 23 March, 26 April and 7 June 2000. The total nut in shell (NIS) harvested from each datum tree was weighed in the field and sub-samples of 2 kg were returned to the laboratory for dehusking, drying, cracking and assessment of fruitspotting bug damage, maturity and kernel weight.

To help in identifying factors that might contribute to crop losses, several variables were recorded throughout the 1999/00 season. At the beginning of the season we recorded the average number of flowers present on each raceme and as the racemes set nuts we monitored nut set and the number of racemes per branch.

Results and discussion

In Blocks A and C an application of endosulfan was recommended and applied in the last week of September when approximately 30% of the trees had fallen nuts bearing damage from fruitspotting bugs (Figure 42). Although similar damage levels were recorded in Block B, an insecticide application was withheld because the trees were still in the process of shedding nuts during the natural nut drop, and it was losses that occur at this time that were of particular interest. Between 29 September and 5 October the trees dropped 76% of the total nuts lost throughout the whole season (Figure 42). Because endosulfan was not applied to Block B, damage levels continued to increase and within three weeks 100% of the trees had damaged nuts under them with a significant proportion of the total nuts damaged by fruitspotting bugs (Figure 42). Two applications of β-cyfluthrin (Bulldock®) were made to all blocks on 19 October and 8 November 1999 (Figure 42). No further sprays were applied during the season. Fruitspotting bug damage levels remained high during the week following each insecticide application. This was expected however, since it is now known that although most nuts fall within a few days of being damaged, it may take up to a week for all damaged nuts to fall (Figures 40 & 41). Approximately two weeks after each insecticide application, fruitspotting bug

damage levels dropped to around 20%. In the middle of December damaged green nuts were difficult to find on the ground. Those that were located were smaller and presumably resulted from late season flowering.

The density of nuts on the ground under the trees in Block B was visibly much greater than that in Block A. The crop load in Block B towards the end of the season was also noticeably sparse. These observations translated into real and significant differences at harvest (Table 29). Most apparent was the decrease in total yield that apparently resulted from the missed early spray. NIS damage was also significantly higher in Block B but kernel recovery was unaffected. Block B was significantly different to the other blocks for all measured parameters except kernel damage on each of the three harvests as well the total harvest.

The wide disparity in kernel maturity among the three blocks is somewhat disconcerting. Since the level of kernel damage was no different to the other blocks, it seems unlikely that fruitspotting bugs could have been responsible for that immaturity and suggests that some other non-insect factors may also have had some influence on the result. Actual nut counts of the 2 kg NIS samples from each tree were not made. Had this been done it may have confirmed our observation that the average nut size from trees in Block B was considerably less than for those in Blocks A and C. Mr Eric Gallagher, a research assistant with over 20 years experience in macadamia and who assisted with the harvests expressed an opinion that there was perhaps some nutrient deficiency in that block. This is not presented as a defence for the reduced yield which was definitely affected by fruitspotting bugs. However, the extent of the measured reduction may have been influenced to some extent by non-bug factors. Taking this into account, the conclusion from the trial was that heavy early fruitspotting bug infestations can cause sufficient damage and green nut drop to significantly reduce final yields. However, the actual number of bugs or the number of bug days required to cause the minimum economic yield loss that would require control action, is still not known.

Table 29: Comparison of various parameters for three blocks of macadamias when one early spray was deleted from one block.

	Yield NIS per tree (kg)	% kernel recovery	Percent NIS damage	Percent immature
Block A	15.28 b	32.27 a	2.451 a	8.091 a
Block B	8.55 a	30.10 b	4.038 b	14.608 b
Block C	14.58 b	32.90 b	1.567 a	5.370 a
LSD	3.088	0.9176	1.029	3.983

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

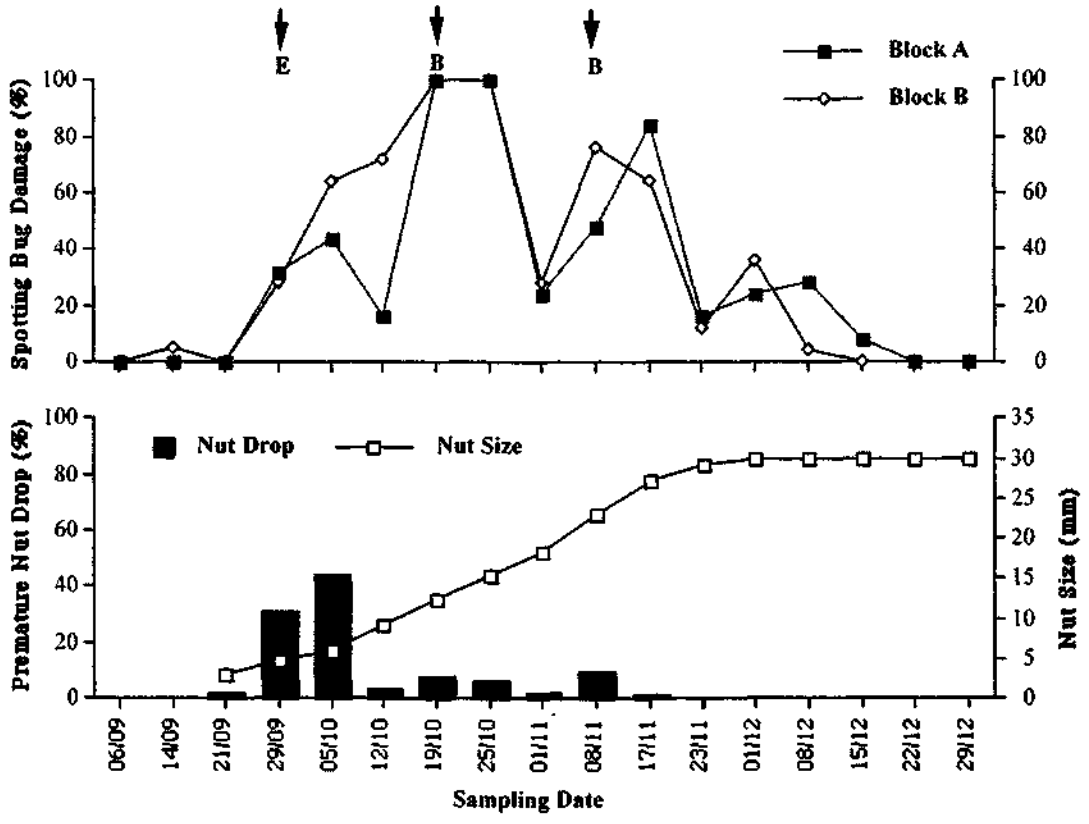


Figure 42: Fruitspotting bug damage expressed as a percentage of the total number of trees with damaged nuts under them. Premature nut fall is expressed as a percentage of the total nuts collected at the base of the trees throughout the season. One Endosulfan (E - block A only) and two Bulldock (B - blocks A and B) sprays were applied during the 1999/00 season on the occasions shown.

14.3.4 Fate of flowers and nuts

Five hundred and seventy-six racemes were randomly tagged and examined in detail on cv.344 at Palmwoods in 1999. The number of flowers on each raceme was counted in the field. Each raceme produced an average of 210 flowers. These same racemes were revisited in the middle of September. Further assessment revealed that those racemes had set an average of 3.4 nuts (range 1 - 24, n = 576). Throughout October and November the nut load gradually decreased until there was an average of only 1.6 nuts on each raceme (range 1 - 9, n = 576). Unfortunately, nut set on its own does not accurately reflect the impact of natural nut loss. Many racemes failed to set or hold a single nut. By the middle of November only 489 (21%) of the racemes on 200 branches that had produced 2351 racemes tagged at flowering, had any nuts on them.

By applying these data to a hypothetical tree the percentage of flowers that developed into mature nuts can be estimated. To do this, it is assumed that the hypothetical tree has 100 racemes. If each raceme produces 210 flowers the tree will have produced around 21,000 individual flowers. We know that approximately 80% of those racemes will fail to set a single nut, leaving only 20 racemes for potential nut production. If each raceme produces an average of 1.6 nuts the tree will produce roughly 32 nuts. That is, 0.2% of the flowers will develop into mature nuts, a figure comparable to the 0.3% quoted by Nagao and Hirae (1992). The bottom line is that 99.8% of the flowers will fail to produce

a nut. That is why we have believed that a more flexible approach to early fruitspotting bug control might be adopted, but determining the critical cut-off time presents a difficult task. Crop loss will no doubt remain a controversial topic and will continue to attract considerable attention from growers and researchers alike. In order to develop reliable economic injury levels a detailed crop loss assessment is essential. We believe that it is time some basic entomological studies were conducted to determine the extent of damage and how each of the major pests affects yield, what are their interactions with each other and the physiological processes of the tree, and what are the imperatives for initiating control at certain phases of crop development.

14.4 Custard apple

Custard apples responded to fruitspotting bug damage in much the same way as did avocados (Figure 43). It took up to a couple of weeks for small and medium sized fruit to abort. Approximately 90% of the small damaged fruit had dropped by the second week. If the fruit had not dropped at that stage they were retained until the eighth week when observations ceased (Figure 43). Natural fruit drop was relatively high for small fruit with approximately 30% of the control fruit aborting for no apparent reason. Only 36% of the medium sized fruit dropped when damaged. This was almost certainly due to the bugs, as none of the control fruit in that size class aborted (Figure 43). Although none of the damaged large fruit dropped during the eight-week sampling period, the feeding sites were clearly visible. Damaged fruit invariably went on to develop fruit rot. Although the damaged small and medium fruit continued to increase in size, they were deformed and unsuitable for the sale.

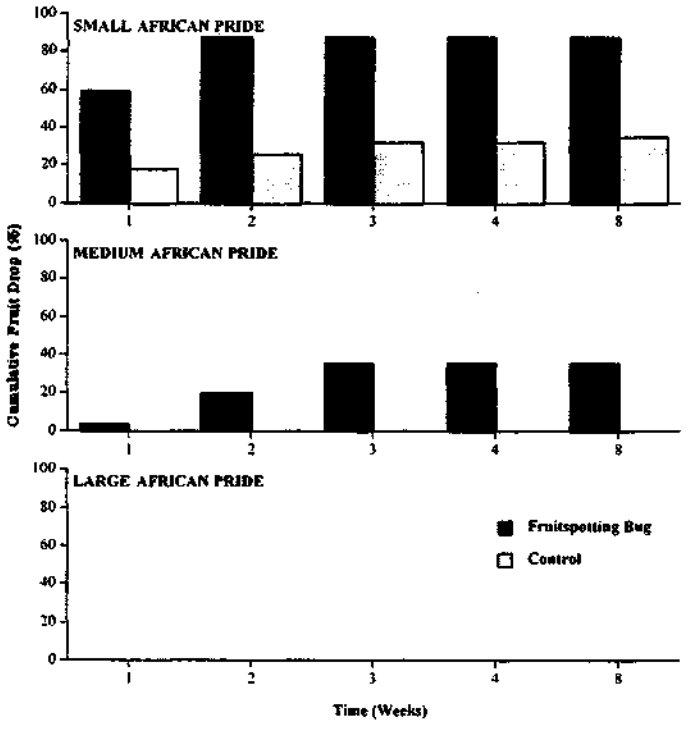


Figure 43: Cumulative African Pride fruit drop expressed as a percentage of fruit exposed to spotting bugs at different stages of development. Fruit were either caged with (Fruitspotting Bug) or without spotting bugs (Control).

14.5 Non-cage studies of natural bug infestations and related avocado fruit drop in the field

Introduction

It is well known that some fruits such as macadamia and lychee that are attacked by fruitspotting bugs, shed that fruit if the damage is inflicted at an early stage of fruit development. The result of such damage in avocado has not been recognised as being so clear-cut and because the perception has generally been that most damaged fruit is retained on the tree, the full extent of early fruit damage has probably not been realised. This study was undertaken to attempt to quantify the extent and fate of small avocado fruit damaged by fruitspotting bugs.

Methods

Each day after fruit-set and commencing on 21 September 1998, pea-sized to marble-sized fruit that exhibited fresh damage from fruitspotting bugs on cvs. Pinkerton and Fuerte trees growing on Maroochy Research Station, were identified with a numbered, dated label. Each week, the number of labelled fruit that had fallen, was recorded. From 30 November 1998, the week after natural fruit shedding commenced, all fallen fruit from beneath unsprayed avocado trees at MRS were collected at approximately weekly intervals and assessed for fruitspotting bug damage. During the peak of this period, one sample was taken from a commercial, sprayed orchard at Woombye and a similar assessment was carried out.

Results and Discussion

Of the fruit damaged when they were pea-sized, 92.3% had fallen from the tree within four weeks of the damage being sustained. Fruit that were slightly larger than this when damaged ie. marble-sized, remained attached to the tree for another three weeks, but gradually fell from then until the period of natural shedding, which saw all of the early damaged fruit fall. During this time, previously undamaged fruit continued to be attacked by the bugs. The period of natural fruit shedding commenced around 23 November and continued until about the middle of January. During this period, even though fruit damaged by the bugs had attained a reasonable size, many of them fell from the tree and in commercial orchards would most likely have been overlooked or ignored because they were part of the natural fruit drop. The number of fruit assessed on each date and the proportion of damaged fruit amongst them are shown in Table 30. The data reveal that even in January when fruit are two-thirds their final size, 38% of shed fruit were bug-damaged.

In the Pinkerton trees bug damage was confined to the early fruit-set period, before endosulfan sprays were applied. After an initial high rate of loss of damaged fruit ie. 3-4 per week of the 28 labelled damaged fruit, by 21 December the attrition rate had dropped to one per week, and it ceased on 20 January. Only one labelled fruit damaged in early October remained on the tree at the end of March. Similarly in the Fuerte trees, all of the fruit damaged at marble-size and below had fallen by 20 January.

Table 30: Proportion of natural avocado drop damaged by fruitspotting bugs at Maroochy Research Station

	Pinkerton – 7 endosulfan sprays			Fuerte - unsprayed		
	No. fallen	No. damaged		No. fallen	No. damaged	Percent damaged
23 Nov	30	2	**6.7**	45	14	**31.1**
30 Nov	26	3	**13.0**	243	46	**23.3**
9 Dec	No sample	-	-	387	86	**28.6**
14 Dec	77	10	**13.0**	202	52	**25.7**
21 Dec	70	11	**15.7**	283	67	**23.4**
6 Jan	50	4	**8.0**	171	65	**38.0**
Average			**11.3**			**28.3**

These data are interesting from a couple of points of view. Even though the Pinkerton tree received seven sprays of endosulfan over the sampling period ie. at a frequency of slightly less than fortnightly, significant bug damage was still evident. In the unsprayed Fuerte, a consistent 23% to 30 % damage level was recorded in fallen fruit right through the sampling period. This spanned only the period of natural fruit drop. Damaged fruit continued to fall after the general drop had ceased, although the extent of this late fall was not measured. In this unsprayed situation, the final level of fruitspotting bug damage on the fruit that remained on the tree exceeded 60%. When this is linked with the earlier fruit that fell, the total toll inflicted by the bugs was severe.

The extent of the early fruit drop especially of the very small fruit, has a number of implications. Firstly, growers usually assess the success of their pest control strategy for the season on the basis of damage recorded at picking or in the packing shed. Data such as appear in Table 29 have never before been obtained and it has generally been assumed that once fruit progresses beyond a certain growth stage that has not been defined, it will remain on the tree regardless of its being damaged by fruitspotting bugs. Hence growers have believed that what they see in the trees or the shed at the end of the season is the total of the damage caused to the crop by fruitspotting bugs. This is obviously not so, and the data reveal that despite its status of being a major pest and capable of causing much damage, the real extent of the damage caused by fruitspotting bugs has probably been significantly underestimated because many of the damaged fruit disappear before harvest. This would be particularly true for damaged fruit in the top of tall trees where, even if a grower did inspect his trees for damage throughout the season, he may not have seen those fruit.

The acquisition of this information leads to the question, 'What does it all actually mean in terms of real crop loss?' The answer to this is not clear-cut, since it is a fact that many fruit will always be shed naturally. What we now need to know is what proportion of the damaged fruit that were shed during natural thinning, might have been part of that thinning process had it not been damaged. The same question arises in macadamias, lychees and other fruits that shed excess fruit. It may be that (a) the **damaged fruit would not have fallen had it not been damaged** (b) the **damaged fruit automatically becomes part of the natural fruit drop** and each damaged fruit being predisposed to abscission, takes the place of an undamaged fruit and thus saves an equivalent number from natural attrition or (c) **fruit that are predestined to be shed** are borne on certain points of the tree and because of their position **will be shed regardless of whether they**

are damaged or not. In the latter case only a certain proportion of damaged fruit would be expected to make up part of the natural drop, but they may fall anyway because of the damage inflicted on them. The actual figure is not known and cannot be predicted.

Conclusion

The conclusion is that much more fruitspotting bug damage is incurred than is actually recorded, and that fruitspotting bugs are an even greater problem than many growers think. Growers may also be under the illusion that their attempts at control are providing reasonable results when in fact, they may not be doing that. There is a need also to determine the relationship between the fate of fruitspotting bug damaged fruit and naturally shed fruit during the season since, if damaged fruit substitutes for undamaged fruit in the natural drop, there is little point in applying bug controls to prevent that damage.

15. Fruitspotting bug damage to avocados at the tree and fruit level

Introduction

The feeding behaviour, damage expression and intra-tree distribution of fruitspotting bug damage was investigated for the project in research conducted by Mark Wade from the University of Queensland, Gatton Campus as a requirement for his degree course. The experiments were designed to investigate cultivar susceptibility, the time to damage expression on two commercial cultivars and the attractiveness of these to fruitspotting bugs.

15.1 Assessment of fruitspotting bug susceptibility of eight avocado cultivars

Methods

Three hundred and eighty fruit from nineteen trees representing eight cultivars in the Maroochy Research Station avocado block were sampled and assessed for cumulative fruitspotting bug damage on the 20th March 1998. The cultivars with the number of trees sampled for each were: Esther (1), Hazzard (1), Parida 1 (1), Sharwil (1), Whitsell (1), Pinkerton (2), Fuerte (3) and Hass (9). The selection criterion for datum trees was that they carried more than twenty fruit at the time of sampling. The trees had been sprayed regularly every two to three weeks since fruit set with endosulfan and copper oxy-chloride.

On each tree, a random sample of twenty fruit located less than two metres above ground level was selected from around the tree perimeter. The number of damaged fruit and the number of stings externally visible on these fruit was recorded for each sample. Fruit were regarded as damaged if one or more fruitspotting bug stings were externally visible. The mean (+/- se) proportion of damaged fruit per tree was calculated for each cultivar.

Results and discussion

The proportion of damaged fruit on the cultivars Sharwil, Whitsell, Hass, Pinkerton, Esther and Hazzard ranged from 10-20% (Table 31). The proportion of damaged fruit on Fuerte (37%) and Parida 1 (65%) was much greater. These results should be considered in association with data that appear below concerning the expression of damage on thin-skinned cultivars compared to thick-skinned cultivars. Since this assessment was based solely on externally visible damage, some damage on the thick-skinned cultivars may have been missed. Nevertheless, there was certainly a significant difference between the two groups and the data suggest that use might be made of more susceptible cultivars as trap trees.

Separate observations carried out on cv. Pinkerton indicated that it suffers significant damage early, up to the time fruit reaches about 3-4 cm diameter. Fruit damaged at this stage is shed so that this assessment probably underestimated the real damage inflicted to that cultivar.

Table 31: Proportion of fruit damaged per tree by natural infestation of fruitspotting bugs at Maroochy Research Station

Cultivar	Number of Fruit	Mean (+/-se) proportion (%) of damaged fruit per tree
Sharwil	20	10 (0)
Whitsell	20	10 (0)
Hass	180	10 (3)
Esther	20	17.5 (7.5)
Hazzard	20	20 (0)
Pinkerton	40	20 (0)
Fuerte	60	36.7 (1.7)
Parida 1	20	65 (0)

15.2 Damage evaluation of harvested Fuerte avocados from a sprayed and non-sprayed block

Methods

Sprayed block

On April 2nd 1998, fruitspotting bug damage was assessed on a random sample of 160 Fuerte fruit discarded in a once over harvest by a collaborating avocado grower at Nambour. The sample weighed 38.4 kg, with an average fruit mass of 240 grams. Approximately 225 kg (11.1%) of fruit were discarded from 2025 kg of fruit harvested from twelve trees. Fruit not discarded on the farm were sent to a cooperative pack-house to be sorted and packed and the remaining damaged fruit discarded.

Fruit were sprayed every two weeks with endosulfan from fruit set up until three weeks prior to harvest. For each fruit sampled the entire surface was examined visually to determine the primary cause of damage warranting discard at harvest. Fruit damage was categorised under three major criteria:

- infection by *Glomerella cingulata*, causing anthracnose
- fruitspotting bug damage - a combination of fresh (cracked), old (not cracked) and stings with secondary anthracnose infection in the same site
- other insect damage, mechanical injury, sunburn, size, shape and rub

The results were presented in a table showing the number of fruit in each category listed as a percentage of the total number of damaged fruit sampled.

Non-sprayed block

Damage was evaluated on a sample of one hundred mature cv. Fuerte avocado fruit. The fruit were picked on 25 May from one non-sprayed tree in the MRS orchard at Nambour. Fruit were randomly picked from over the whole tree. Fruit at the top of the tree were

reached using a cherry picker. Each fruit was weighed and the surface visually assessed for the primary cause of damage. The number of fruit was totalled in each of following four major categories:

- fruitspotting bug - combination of fresh (cracked), old (not cracked) and stings with secondary anthracnose infection in the same site
- anthracnose
- other insect damage, mechanical, sunburn and rub
- not damaged

For each 'damaged' category the number of fruit was calculated as a percentage of the total number of damaged fruit sampled. Also, in each category the number of fruit was calculated as a percentage of the total number of fruit sampled (damaged + not damaged). Mean (+/- se) fruit mass and total fruit mass was calculated.

Results and discussion

Of the discarded fruit in the non-sprayed block, 78.2% could be attributed to fruitspotting bug damage. In contrast, damage levels were substantially lower in the sprayed block, with only 45.6% of fruit damaged by fruitspotting bugs (Table 30). Anthracnose was also a major problem on Fuerte, with incidence levels varying between 17% and 20% (Table 32).

As a component of fruitspotting bug damage, fruitspotting bug damage that allowed anthracnose to develop in the same site comprised 41.4% and 32.5% of total damaged fruit in the non-sprayed and sprayed block respectively (Table 33). The incidence of old fruitspotting bug was considerably lower at 12.5% in the sprayed block compared to 35.6% in the non-sprayed block (Table 33). Fresh fruitspotting bug damage was minimal and ranged from 0.6 to 1.1%.

Table 32: Percentage of discarded fruit damaged by insects and diseases on sprayed and non-sprayed Fuerte trees

	No. of fruit	Spotting Bug	Anthracnose	Other
Non -sprayed	100	78.2	19.5	2.3
Sprayed	160	45.6	16.9	37.5

Table 33: Percentage of discarded fruit damaged byfruitspotting bugs on sprayed and non-sprayed Fuerte trees.

	No. of Fruit	Fresh Bug damage	Old Bug damage	Bug plus anthracnose	Total Bug
Non-sprayed	100	1.1	35.6	41.4	78.2
Sprayed	160	0.6	12.5	32.5	45.6

15.3 Comparison of damage levels between a hot-spot and another area of the farm

Block K

On 3-4 February 1998, five trees from each of rows one and two in Block K in an avocado orchard at Flaxton, were sampled. Two samples, one on the eastern side and the other on the western side of the tree were taken and combined. For each sample in row one, all fruit in a group that could be reached when standing in one position were tagged and labelled. For each sample in row two, twenty of the closest fruit within reach from the ground were again tagged and labelled. In each sample fruit that were damaged by fruitspotting bugs were picked irrespective of the number of external stings, and returned to the laboratory for examination. These fruit had been damaged between fruit set and the 3-4 February 1998. The remaining fruit were not damaged.

Three weeks later on 24 February, the level of fresh damage in block K was determined by picking the newly-damaged fruit in each tagged selection. For each sampling date the proportion of damaged fruit on each tree was calculated as a percentage of the number of tagged damaged fruit divided by the total number of tagged fruit (damaged plus not damaged).

Block M

On the 24 February 1998 twenty samples of fruit were selected on approximately fifteen trees in four rows in block M, to look at existing damage levels. Each sample consisted of twenty of the nearest fruit within reach form a set standing position, tagged and labelled. Damage fruit were picked from each selection and returned to the laboratory for further examination. In each sample the proportion of damaged fruit was calculated using the same method as for Block K. The mean (+/- se) proportion (%) of damaged fruit per sample in Block M was calculated and compared with that for Block K.

Results and discussion

In Block K, 21% of the fruit were damaged by fruitspotting bugs in the period from fruit set in September-October 1997 to the 3-4 February 1998. In the same block, 9% of fruit that were clean on 3-4 February were damaged when the trees were re-sampled on the 24th February (Table 34). In contrast, damage levels sustained in Block M from fruit set until 24 February were only 6.5%. Thus damage attained in approximately four months in Block M was equivalent to damage sustained in three weeks in Block K. The comparison of damage levels in the two blocks demonstrates the difference between hotspots and less susceptible areas of an orchard from both a whole-season and peak season point of view.

Table 34: Mean (+/- se) percentage of fruitspotting bug damaged fruit per tree.

Date	Block K	Block M
3rd/4th February	21.1 (2.6)	-
24th February	9.0 (2.4)	6.5 (1.8)

15.4 Comparison of damage levels within a hot-spot between the top and bottom sectors of avocado trees

Methods

On 3 March 1998, five trees from each of rows one and two in Block K were sampled to assess fruitspotting bug damage. On each tree two separate samples of the twenty fruit were picked regardless of condition, from two sectors on the outside of each tree - the top (greater than two metres high) and the bottom (less than two metres). A ladder was used to reach the fruit from the tops; fruit from the bottom were within reach from the ground. The 400 fruit were returned to the laboratory at MRS and the number of externally and internally visible stings on each fruit was counted. Fruit were peeled with a vegetable peeler to reveal the number of internal stings.

For each of rows one and two, and for the top and bottom of the trees, the mean (+/- se) proportion of fruit with external and internal bug damage was calculated per tree. Also determined was the mean (+/- se) number of externally visible and then internally visible stings on the damaged fruit at each position. The percentage of stings expressed externally was calculated by dividing the mean external number of stings per fruit by the mean internal number of stings per fruit at each sampling position.

To determine the accuracy of predicting the actual number of stings on a fruit using external sting counts, a comparison was made between externally visible sting counts and internally visible (actual) sting counts on each fruit. Fruit were categorised into three classes, which were expressed as a percentage of the total fruit sampled.

1. Under-estimated, where the number external stings was less than the number of internal stings.
2. Exact, where the number of external stings equalled the number of internal stings
3. Over-estimated, where the number external stings was greater than the number of internal stings.

As a measure of fruit growth/development the length and diameter was recorded on a sub-sample of one hundred of the fruit collected.

Results and discussion

In all cases fruitspotting bug damage in the top of trees was consistently higher than that in the bottom (Table 35). When assessed on external damage symptoms on the fruit, the mean proportion of damaged fruit in the top of trees ranged from 69% to 76%, far exceeding the 39% recorded in the bottom sector. Following this trend, the number of fruitspotting bug stings on damaged fruit in the top was greater (3.4 to 6.4) compared to 2.5 to 2.9 stings per fruit in the lower sector. Substantial differences were apparent in the level of fruitspotting bug damage when this was assessed separately on external and internal symptoms. Only 64.8% of total fruitspotting bug stings were visible externally, and based on this assessment 55.8% of all the fruit were damaged by fruitspotting bugs. The real level of damage was far greater, with 66.8% of all fruit damaged when assessed with the skin removed.

Table 35: Comparison of spotting bug damage within a hot-spot (Block K). Fruit were sampled from Hass avocado trees at Flaxton in March 1998. Spotting bug damage was identified from external and internal observations.

Position	% damaged fruit/tree	% with internal damage	No. external stings per fruit	No. internal stings per fruit	Percent total stings expressed externally
Tree top Row 1	69	84	6.4	9.6	66.7
Tree top Row 2	76	81	3.4	5.7	59.6
Tree Bottom Row 1	39	54	2.9	4.9	59.2
Tree Bottom Row 2	39	48	2.5	3.4	73.5
Mean	55.8	66.8	3.8	5.9	64.8

Only 41% of the fruit sampled had an external visible number of stings equal to the internal (actual) number of stings (Table 36). The external condition under-estimated the true state on over half of the fruit sampled. Average fruit size was 59.9 mm (+/- 0.4) in diameter by 85.5 mm (+/- 0.7) in length [N=100].

Table 36: Percentage of fruit in three outcomes based on external and internal fruit observations. Fruit were randomly sampled on Hass avocados from Flaxton in March 1998. spotting bug damage was identified from external and internal observations.

Fruit condition[N=400]	Percentage of Fruit
Under-estimated (External < Internal)	52
Exactly estimated (External = Internal)	41
Over-estimated (External > Internal)	7

15.5 Fruitspotting bug damage expression in Fuerte and Hass avocados

Methods

Laboratory preparation

Experimental insects: Fruitspotting bugs were conditioned by feeding them on Fuerte avocado fruit. The insects were placed in two cages, 300 x 300 x 600 mm cages, each containing three fruit suspended by string from the top of the cage to simulate fruit hanging from a branch.

Field experiments Nambour

Twenty-four undamaged fruit of similar size on one tree each of Fuerte and Hass, were randomly selected from around the outside of the tree. The fruit were cleaned with water to remove any chemical residue from the last application of endosulfan and copper oxy-

chloride fourteen days earlier. Each fruit was caged in a 200 mm wide by 400 mm long white polyester sleeve for the duration of the experiment.

Treatments were:

1. Hass control: N=12, no bugs added
2. Hass and *A. lutescens*: N=6, bugs caged for 3 days
3. Hass and *A. nitida*: N=6, bugs caged for 3 days
4. Fuerte control: N=12, no bugs added
5. Fuerte and *A. lutescens*: N=6, bugs caged for 3 days
6. Fuerte and *A. nitida*: N=6, bugs caged for 3 days

The treatments #2 and #3 are referred to as Hass bugs. Similarly the treatments #5 and #6 are referred to as Fuerte bugs.

In the bug treatments, one bug was caged on each fruit and allowed to feed for three days. Insect mortality was recorded daily during the three day feeding period. The results for fruit where the bug died were not included in the data set. The cumulative number of visible stings was recorded on each fruit at day zero, day three and then every second day until day twenty-one.

The cultivar susceptibility of Hass and Fuerte was assessed by comparing the mean number of external stings per fruit at day twenty-one from all fruitspotting bug treatments. To determine the time it takes for damage to express, the mean cumulative number of external stings per fruit was compared on the control and bug treatments for each cultivar at days zero, three, five, seven, fourteen and twenty-one. This same data was expressed as a percentage of total external stings at Day 21.

On Day 21, all fruit were harvested and peeled with a vegetable peeler to reveal the actual number of stings. The percentage of stings expressed externally at Day 21 on each bug treatment was calculated as the mean number of external stings per fruit divided by the mean number of internal stings at Day 21. The average time in days for stings to appear was calculated for each bug treatment.

For Hass and Fuerte the mean number of stings at Day 21 for the treatments lutescens and nitida were compared to determine any difference in feeding preference of each species of bug. The visual appearance of fresh damage was documented.

Fruit phenology parameters: Fruit growth measurements relate the stage of fruit growth to damage appearance and expression during the twenty-one day study. A random sample of twelve fruit each was taken for each cultivar at the start and end of the field study. Mean fruit length and diameter, mass and dry matter were measured. Dry matter is related to oil content, where 21% dry matter is approximately equal to 12% oil content. Dry matter was calculated by taking a 50.00 gram (Hass) or 100.00g (Fuerte) sample of grated flesh from each fruit and drying it in an oven for 24 hours at 60 degrees Celsius. The mass of each sample was recorded again after drying. Percent dry matter accumulation was calculated by dividing dry weight by wet weight and multiplying by 100.

Results and discussion

Cultivar susceptibility

At Day 21 the treatment Fuerte Bugs had the highest number of fruitspotting bug stings with 11.7 mean stings per fruit. The Hass Bugs treatment suffered less damage, having fewer than half the number of stings per fruit (Table 37).

Sting expression

The very small number of fruitspotting bug stings on the Hass control (0.1) and Fuerte control (0.2) fruit at Day 3 and Day 21, confirms that stings in the Bug treatments were due to the imposed experimental effect of caged bug feeding. From Day 3 to Day 21, the mean number of stings on Hass Bugs was 2.5 to 4 times lower than the mean number on Fuerte Bugs. At Day 3 the mean number of stings per fruit on Hass Bugs was 2.2, compared with 9.0 on Fuerte. The same number of external stings per fruit was recorded on each treatment at Day 14 and Day 21, suggesting a cessation in the number of new stings being expressed externally.

The rate at which stings express as a percentage of total external stings over time for Hass Bugs, was slower than for Fuerte Bugs. At Day 3, 77% of total stings had expressed on Fuerte Bugs compared with only 46% on Hass Bugs.

Table 37: Mean number of fruitspotting bug stings per fruit on the treatments Hass Control, Fuerte Control, Hass Bugs and Fuerte Bugs, from 3 days feeding. The numbers in brackets are the mean number of stings (bug treatments) expressed over time as a percentage of total external stings at Day 21.

Treatment (N)	Time (days)					
	Day 0	Day 3	Day 5	Day 7	Day 14	Day 21
Hass Control (12)	0.0	0.1	0.1	0.1	0.1	0.1
Fuerte Control (12)	0.0	0.2	0.2	0.2	0.2	0.2
Hass Bugs (10)	0.0	2.2	3.7	4.3	4.8	4.8
	(0.0)	(45.8)	(77.1)	(89.6)	(100)	(100)
Fuerte Bugs (9)	0.0	9.0	10.8	11.6	11.7	11.7
	(0.0)	(76.9)	(92.3)	(99.1)	(100)	(100)

Percentage of stings externally visible

As a percentage of total internal (actual) spotting bug stings per fruit, 83% had expressed externally in the treatment Fuerte Bugs. In contrast, stings are more difficult to find on Hass, with only 54.5% externally visible (expressed) in Hass Bugs after 21 days (Table 38). This data reinforces that presented elsewhere in this document concerning the risk that Hass fruit damaged by fruitspotting bugs poses to quality control in market packs of avocado fruit.

Table 38: Mean number of external and internal fruitspotting bug stings per fruit, and the percentage of total stings expressed externally at Day 21.

Treatment (N)	Mean no. external stings per fruit	Mean no. internal stings per fruit	Percentage of total stings expressed externally
Hass Bugs (10)	4.8	8.8	54.5
Fuerte Bugs (9)	11.7	14.1	83.0

Average time for a stings to express externally

The average time for fruitspotting bug stings to express externally was calculated as 2.2 days for Fuerte Bugs and 3.8 for Hass Bugs.

Feeding preference between banana-spotting bug and fruitspotting bug

The mean number of stings per fruit on Hass and Fuerte was lower on the lutescens treatment compared to the nitida treatment. Hass lutescens fruit had a mean of 3.3 stings compared to Hass nitida with 7.0 stings. Fuerte lutescens recorded a mean of 9.8 stings compared to 13.2 on Fuerte nitida. These data suggest that *A. nitida* has the potential to inflict greater damage on all avocado cultivars than *A. lutescens* and in fact supports both laboratory and field ono-experimental observations that the amount of damage per unit time inflicted by *A. nitida* is indeed greater than for *A. lutescens*.

Fruit growth measurements

Fruit growth measurements are presented in Table 39. The value of all fruit characteristics increased in 21 days. Compared to Hass, Fuerte was substantially larger in each value for all fruit characteristics and showed a greater rate of increase in diameter, length and mass. The rate of increase in dry matter and oil content was higher in Hass.

Table 39: Mean fruit growth measurements at Day 0 and 21. Fruit were sampled from Hass and Fuerte avocados at Maroochy Research Station in March-April 1998.

Fruit Growth	Hass [N=12]		Fuerte [N=12]	
Measurements	Day 0	Day 21	Day 0	Day 21
Mean fruit diameter (mm)	60.2	61.2	71.3	73.1
Mean fruit length (mm)	77.8	80.2	118.0	124.5
Mean fruit mass (g)	146.4	146.8	286.2	313.2
Oil content of fruit (%)	7.5	8.9	10.6	10.8
Mean fruit dry matter (%)	19.7	21.1	20.8	21.0

16. Technology transfer

Information on the progress and results of research conducted was extended to the grower community and other interested persons through the production of quarterly reports.

Quarterly Reports 1-8 were posted to mailing list recipients, with relevant sections extracted from these and published in Industry Newsletters - **'Talking Avocados', 'Australian Macadamia Society Newsletter', 'The Custard Apple', 'Sunshine Coast Avocado Growers' Association Newsletter', Sunshine Coast Subtropical Fruits Association Newsletter'.**

A fruitspotting bug webpage was established at www.dpi.qld.gov.au/qhi/fsb on which was posted the quarterly reports as well as additional information about the pests.

The information has been made available for inclusion in **'Avoman'** and **'Agrilink'** and presentations were made at many **conferences and meetings:**

July 1997 Presentation to **Sunshine Coast Subtropical Fruits Association Field day, Pomona – G.K.W.**

22 August 1997 Presentation to **Tableland Mac Group Meeting, Marnane's Farm, Atherton - H.A.F.**

February 1998 Presentation to **Tableland Mac Group Meeting, TableTop Nuts, Wongabel - H.A.F.**

September 1998 paper presented at **Australian Macadamia Society Annual Conference, Gold Coast - G.K.W.**

11 March 1998 Presentation to **Macadamia Group Meeting, Gympie - G.K.W. & S.A.H.**

28 May 1998 Presentation to **Macadamia Crop Protection RD & E Workshop, MHRS - G.K.W. & S.A.H.**

30 May 1998 Filmed segment for **'Totally Wild', Channel 10 - G.K.W. & S.A.H.**

16 June 1998 Paper and poster presented at **International Conference of Integrated Pest Management, Guangzhou, China – G.K.W.**

28 July 1998 Presentation to **Atherton Tableland Avocado Growers' Association Meeting, Walkamin - H.A.F.**

26 August 1998 Presentation to **Macadamia Field Day, Garrick Smith's Farm, Malanda - H.A.F.**

18 September 1998 Paper presented at **Australian Macadamia Society Annual Conference, Gold Coast - G.K.W.**

13 November 1998 Presentation to **Mt. Tamborine Avocado Growers' Association Field Day - G.K.W. & S.A.H.**

17 March 1999 Presentation at **Walkamin Research Station Open Day - H.A.F.**

23 March 1999 Meeting with **AAGF re new project proposal – G.K.W. & S.A.H.**

13 April 1999 Contribution to the **Custard Apple Newsletter** *'The dilemma of controlling fruitspotting bugs in custard apples with chemicals'* - **G.K.W.**

7 April 1999 **QHI Review of Macadamia Projects** (De Bono's 'Six Hats') - **G.K.W. and S.A.H.**

22 April 1999 **TV segment** - Fruitspotting bugs in custard apples at Rochedale, **'Brisbane Extra', Channel 9 - G.K.W.**

9 June 1999 Presentation to **Avocado Field Day, Glasshouse - S.A.H. and G.K.W.**

13 July 1999 Presentation to **Australian Custard Apple Conference, Twin Waters - G.K.W.**

12 August 1999 Presentation to **Tableland Mac Group Meeting, Col Cummin's Farm, Kairi - H.A.F.**

17 August 1999 **Review of project conducted by HRDC** at Alstonville, NSW - **G.K.W., H.A.F., S.A.H., R.J.P., G.C. and C.M.**

13 September 1999 Paper presented at the **6th Australian Lychee Conference, Twin Waters - G.K.W.**

29 September 1999 Paper presented at the **First International Macadamia Symposium in Africa Macadamia Growers Association, Nelspruit, Mpumalanga, South Africa - G.K.W.**

19 October 1999 Paper presented at the **4th World Avocado Congress, Uruapan, Mexico - G.K.W.**

29 October 1999 Presentation to the **Annual Conference of the Australian Entomological Society, Canberra - S.A.H.**

3 February 2000 Article in **Queensland Country Life** re spray timing in macadamias - **S.A.H.**

13 January 2000 Presentation to **Meeting of the Atherton Tableland Avocado Growers' Association - G.K.W.**

22 August 2000 Poster presentation at the **XXI International Congress of Entomology, Foz do Iguassu, Brazil G.K.W.**

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Trevor Grant, Diddillibah - Trial orchard
Ken and Muriel Webb, Woombye - Trial orchard
Ralph and Brenda Hoskin, Palmwoods - Trial orchard
Keith Mosely, Flaxton - Trial orchard
Terry Mather, Blackbutt - Trial orchard
Lyn and Grahame Adamson and Gary Burnett, Palmwoods - Trial orchard
Henry Drew, Palmwoods - Crop Consultant
Eric Gallagher, Bli Bli - Research assistant
Bill and Jane Thompson, Glasshouse - Custard apple data
Peter McKenzie, Diddillibah - Trial orchard
Iqbal Singh, Diddillibah - Trial orchard
Lachlan Waite, Buderim - Casual assistant
Lianda Garvey - Casual Assistant
N. Price - Temporary Research Assistant
R. Wilson - Casual Resistant
John Rees - Experimental orchard
Lloyd Jones - Experimental orchard
Leasie Felderhof - Experimental orchard
Bill Marnane - Experimental orchard
Dianne Wellington - Experimental orchard
Burdekin Agricultural College - Experimental orchard
The Manager and staff of Walkamin Research Station - Experimental orchards
Michael Hyde, Maroochy Research Station - Equipment construction
Rob Juster, Maroochy Research Station - Equipment construction

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Appendix 1

PROJECT: *'Ecology and behaviour of fruitspotting bugs'*

Request for Information

As part of the HRDC and Industry-funded project 'Ecology and behaviour of fruitspotting bugs', we are requesting growers to supply us with any information you may have, based on records or experience, of fruitspotting bug (FSB) infestations, environmental conditions which may have influenced their appearance, weather records etc. Following is a series of questions concerning the information we would like you to provide. If your observations are sufficiently brief you can enter them on the form itself or you may attach extra information if you wish. We are interested in the first instance in the topics listed, but would appreciate any relevant information concerning your experience with FSB. If you take the time to provide it, we will use it if possible. Please note that if you don't have or have never had a FSB problem we are just as interested in your situation and data as we are in the others, and will welcome your response. As well as some basic site/weather data we hope to build a general database for the overall problem and how a wide spectrum of growers perceive it.

We are also seeking the assistance of several collaborators spread geographically throughout the production areas affected by FSB and within the various industries, who might help us gather additional information according to a protocol that we will supply. This will involve simple observations and recording. If you would like to be involved, please indicate by ticking the box opposite the appropriate question below. Return of the survey information by November 17 would be appreciated.
We thank you in anticipation and look forward to reporting the results of the research from the project as they come to hand.

Geoff Waite
Principal Entomologist (Project Leader)
for the Project Team

Information requested:

1. Your name and farm address (ie. geographic location, not PO Box numbers)(include phone number please):

2. Crops grown (FSB hosts); area and/or number of trees (an indication of the mix of cultivars would be useful)

3. FSB status in your orchard (please tick):
- never a problem ( )
- minor problem ( )
- occasional serious problem ( )
- always a problem ( )

4. Do you record FSB damage in the field (Yes/No) or at harvest (Yes/No)? If 'yes', could you please attach records of such damage and indicate its source?

5. If you answered 'yes' to the previous question, do you have rainfall records or other weather observations for your property? A copy of records for the years for which you have records would be appreciated (these need only be weekly or monthly totals, not daily!). **Note:** If you answered 'no' to the previous question, this information is not required.

6. If you have records of damage observations on a per block or cultivar basis these would be useful - please attach.

7. Have you observed FSB 'hotspots' (Yes/No) or 'edge-effects' (Yes/No) in any of your blocks?

8. Can you relate these to any of the following? Please tick.
- Surrounding ( ) or adjacent vegetation ( ) (list type of vegetation)

- High points ( ) or low points ( ) in the orchard
- Sheltered areas ( )
- Sheltered areas near windbreaks ( )
- Tall trees ( ) dense trees ( ) tall,dense trees ( )
- Odd cultivars in an otherwise uniform block ( )
- Any other relationships, please specify –

9. What is your experience with the effectiveness of endosulfan?
very effective ( ) moderately effective ( ) useless ( ) variable ( ) good residual activity ( ) no residual activity ( ). Do you always apply it in combination with copper sprays? ( ).

10. Have you tried (Yes/No) or do you use (Yes/No) any other **registered chemicals**?
If 'yes', which ones and how effective were they?

11. Do you know what a FSB looks like? Yes/No
Have you ever seen them **in your orchard**? Yes/No

12. How do you decide when to spray? calendar ( ) see damage ( ) see bugs ( )
If you calendar spray, how often?

When do you commence? What chemical(s) do you use?

If you spray on damage, at what level? eg.
- first sighting ( )
- several fruit damaged on one tree ( )
- odd fruit damaged on a number of trees ( )
- 50 or more fruit damaged on a number of trees ( )
- damage on indicator trees eg. in known 'hotspots' ( )
- other measures (please detail) ( )

13. Do you have any interesting observations re FSB not already described that you think may contribute to our understanding of the pests? If so, please detail (attach if necessary).

14. Would you be prepared to assist the project through carrying out and recording some simple observations for which the protocol will be provided? ( )

Appendix 2

Palmwoods Vegetation Survey Block A

Genus	Species	Common Name	FSB host	Exotic
Baeckea	*virgata*			
Banksia	*spinulosa*			
Callistemon	sp.	Bottle Brush		
Cinnamomum	*camphora*	Camphor Laurel		✔
Cotoneaster	sp	Cotton Easter		✔
Eucalyptus	*grandis*	Flooded Gum	? suspected	
Fraxinus	*griffithi*	Green Ash		✔
Glochidon	*ferdinandi*	Cheese Tree	Yes - A. lutescens	
Grevillea	*robusta*	Silky Oak		
Jacaranda	*mimosaefolia*	Jacaranda		
Melaleuca	*armillaris*	Bracelet Honey Myrtle		
Melaleuca	*bracteatum*			
Melaleuca	*linariifolia*	Snow in Summer		
Melaleuca	*alternifolia*			
Melia	*azedarach*	White Cedar	Yes - A. lutescens	
Quercus	sp.	Oak		✔
Salix	*babylonica*	Willow		✔
Syzygium	*leumannii*	Small Leaf Lilly Pilly		
Tippuana	*tippu*			✔
Ulmus	*paruifolia*	Chinese Elm		✔

Palmwoods Vegetation Survey Block B

Genus	Species	Common Name	FSB host	Exotic
Adiantum	*hispidulum*	Five Fingered Jack		
Alocasia	*macrorrhizos*	Cunjevoi		
Castanospermum	*australe*	Black Bean		
Commersonia	*bartramia*	Brown Kurrajong		
Cordyline	*rubra*			✔
Cryptocarya	sp.		?	
Culcita	*dubia*	Soft Fern		
Elaeocarpus	*obovatus*	Hard Quandong	Yes? - A. nitida	
Elaeocarpus	*grandis*	Blue Quandong	Yes - A. nitida	
Endiandra	sp.	Hairy Walnut		
Ficus	*coronata*	Sandpaper Fig	Yes - A. nitida	
Glochidion	*sumatranum*	Cheese Tree	Yes - A. lutescens	
Gmelina	*leichardtii*	White Beech		✔
Lomandra	*longifolia*	Mat Rush	Yes - A. lutescens	
Lophostemon	*conferta*	Brush Box	?	
Melia	*azedarach*	White Cedar	Yes - A. lutescens	
Neolitsea	*dealbata*	White Bolly Gum	Yes - A. nitida	
Parsonia	*strainea*	Monkey Vine		
Pteridium	*esculentum*	Bracken Fern		
Rhodamia	*trinerviia*	Mallet Wood		
Syzygium	sp.	Lilly Pilly	yes - A. lutescens	
Waterhousia	*floribunda*	Weeping Lilly Pilly		

Palmwoods Vegetation Survey Block C

Genus	Species	Common Name	FSB host	Exotic
Alocasia	*macrorrhizos*	Cunjevoi		
Archontophoenix	*cunninghamiana*	Bangalow Palm	yes - A. lutescens	
Castanospermum	*australe*	Black Bean		
Cissus	*antartica*	Kangaroo Vine		
Cocos	*plumosa*	Queen Palm		✔
Commersonia	*bartramia*	Brown Kurrajong		
Cryptocarya	sp.		yes - A. nitida	
Culcita	*dubia*	Soft Fern		
Diploglottis	*australis*	Native Tamarind		
Elaeocarpus	*obovatus*	Hard Quandong	yes - A. nitida	
Elaeocarpus	*grandis*	Blue Quandong	yes - A. nitida	
Eucaltypus	*grandis*	Flooded Gum	? suspected	
Eucaltypus	*intermedia*	Pink Bloodwood	?	
Ficus	*coronata*	Sandpaper Fig	yes - A. nitida	
Glochidion	*sumatranum*	Cheese Tree	yes - A. lutescens	
Glochidion	*ferdinandi*	Cheese Tree	yes - A. lutescens	
Jacaranda	*mimosaefolia*	Jacaranda		✔
Lomandra	*longiofolia*	Mat Rush	yes - A. lutescens	
Melia	*azedarach*	White Cedar	yes - A. lutescens	
Neolitsea	*dealbata*	White Bolly Gum	yes - A. nitida	
Rhodamia	*trinervia*	Mallet Wood		
Schefflera	*actinophylla*	Umbrella Tree	yes - A. lutescens	
Sloanea	*australis*	Maidens Blush		
Sterculia	*quadrifida*	Peanut Tree		
Syzygium	sp.	Lilly Pilly		

Diddillibah Orchard Vegetation Survey

Genus	Species	Common Name	FSB host	Exotic
Eucalyptus	*microcorys*	Tallowood	? suspected	
Eucalyptus	*rissinifera*	Red Bloodwood	?	
Eucalyptus	*pilularis*	Blackbutt	?	
Eucalyptus	*intermedia*	Pink Bloodwood	?	
Lophostemon	*conferta*	Brush Box	?	
Alocasuarina	*torulosa*	Sheoak		
Cryptocarya	*sp.*		yes - A. nitida	
Alphitonia	*exelsa*	Red Ash	yes - A. nitida	
Syncarpia	*glomuliferea*	Turpentine		
Commersonia	*bartramia*	Brown Kurrajong		
Stenocarpus	*sinuatus*	Fire Wheel Tree		
Melia	*azedarach*	White Cedar		
Glochidion	*sumatranum*	Cheese Tree	yes - A. lutescens	
Polyscias	*elegans*	Celery Wood		
Syzygium	*laehmannii*	Small Leaf Lilly Pilly		
Mallotus	*phillipensis*	Red Kamala	yes - A. nitida	
Elaeocarpus	*reticulatus*	Blue Berry Ash	yes - A. nitida	
Melicope	*elleryana*	Pink Euodia		
Macaranga	*tanarius*		yes - A. lutescens	
Cinnamomum	*oliveri*	Olivers Sassafras		
Eupomatia	*laurina*	Native Guava		
Elaeocarpus	*obovatus*	Hard Quandong	?	
Sloanea	*australis*	Maidens Blush		
Backhousia	*myrtifolia*	Grey Myrtle		
Synoum	*glandulosum*	Scentless Rosewood		
Smilax	*australis*	Barbed Wire Vine		
Cissus	*hypoglauca*	Native Grape		
Cinnamomum	*camphora*	Camphor Laurel		✔
Schefflera	*actinophyla*	Umbrella Tree	yes - A. lutescens	✔
Lantana	*camara*	Lantana		✔
Pteridium	*esculentum*	Bracken Fern		
Culcita	*dubia*	Soft Fern		
Blechnum	*carligenum*	Gristle Fern		
Hovea	*acutifolia*	Hovea		
Dianella	*caerulea*	Flax Lilly		
Geitonoplesium	*cymosum*	Scrambling Lilly		
Acacia	*melanoxylon*	Black Wattle		
Rubus	*molaccanes*	Wild Raspberry		
Relidiostigma	*rhytispermum*	White Myrtle		
Clerodenron	*floribundum*	Lolly Bush		
Archontophoenix	*cunninghamiana*	Bangalow Palm	yes - A. lutescens	

Back Orchard Vegetation Survey

Genus	Species	Common Name	FSB host	Exotic
Eucalyptus	*microcorys*	Tallow Wood	?	
Eucalyptus	*grandis*	Flooded gum	?	
Lophostemon	*conferta*	Brush Box	?	
Cryptocarya	*glaucescens*	Jackwood	?	
Glochidion	*ferdinandi*	Cheese tree	Yes - A.lutescens	
Glochidion	*sumatranum*	Umbrella cheese tree	Yes - A. lutescens	
Cinnamomum	*camphora*	Camphor laurel		✔
Elaeocarpus	*obovatus*	Hard quandong	Yes - A. nitida	
Archontophoenix	*cunninghamiana*	Bangalow palm	Yes - A. lutescens	
Schefflera	*actinophylla*	Umbrella tree	Yes - A. lutescens	✔
Sloanea	*australis*	Maiden's blush		
Blechnum	*indicum*	Swamp water fern		
Culcita	*dubia*	Rainbow fern		
Sticherus	*flabellatus*	Umbrella fern		
Jagera	*pseudorphus*	Foamback		
Waterhousia	*floribunda*	Weeping LilyPily		
Eupomatia	*laurina*	Native guava		
Geitonoplesium	*cymosum*	Scrambling lily		
Acacia	*melanoxylon*	Blackwood		
Cyathea	*cooperi*	Tree fern		
Melastoma	*polyanthum*	Blue tongue		
Passiflora	sp.	Corky Passion Vine	Yes - A. lutescens	✔
Flindersia	*brayleayana*	Qld. maple		
Clerodendron	*floribundum*	Lolly bush		
Polyscias	*elegans*	Celery wood		
Pinus	*radiata*	Pine		✔
Melaleuca	*stypheloides*	Prickly paperbark		
Commersonia	*bartramia*	Brown kurrajong		
Castanospermum	*australe*	Black bean		
Ficus	*benjamima*	Weeping fig		✔
Syzygium	*oleosum*	Blue lilypily		
Parsonsia	*straminea*	Monkeypod		
Cyperus	*sp.*	Sedge		
Melaleuca	*quinquinerva*	Paperbark		
Grevillea	*robusta*	Silky oak		
Ficus	sp.	Fig		
Schinus	*terebinthifolia*	Pepperina	Yes - A. nitida	✔
Ochna	*serrulata*	Mickey mouse plant		
Callistemon	*salignus*	Bottle brush		
Cissus	*hypoglauca*	Native grape		
Millettia	*megasperma*	Native wisteria		
Neolitsea	*dealbata*	White bolly gum	Yes - A. nitida	
Ficus	*coronata*	Sandpaper fig	Yes - A. nitida	
Rubus	*alceifolius*	Wild raspberry		

Flaxton Orchard Vegetation Survey

Genus	Species	Common Name	FSB host	Exotic
Alphitonia	*excelsa*	Red ash	Yes - both	
Flindersia	*australis*	Crows ash		
Diploglottis	*cunninghamii*	Tamarind		
Arytera	*lautereriana*	Corduroy tamarind		
Pittosporum	sp.	Sweet pittosporum		✔
Nicotiana	*glauca*	Wild tobacco		✔
Passiflora	sp.	Passion fruit		✔
Cinnamomum	*camphora*	Camphor laurel		✔
Ligustrum	*lucidum*	Privet		✔
Geitonoplesium	*cymosum*	Scrambling lily		
Lantana	*camara*	Lantana		✔
Castanospermum	*australe*	Black bean		
Archontophoenix	*cunninghamiana*	Bangalow palm	Yes - A. lutescens	
Cyathea	*cooperi*	Tree fern		
Elaeocarpus	*obovatus*	Hard quandong	Yes - A. nitida	
Acacia	melanoxylon	Blackwood		
Commersonia	*bartramia*	Brown kurrajong		
Alocasia	*macrorrhiza*	Cunjevoi		
Ficus	*coronata*	Sandpaper fig	Yes - A. nitida	
Millettia	*megasperma*	Native wisteria		
Alpinia	*caerula*	Native ginger		
Sloanea	*australis*	Maidens blush		
Araucaria	*bidwillii*	Bunya pine		
Solanum	*mauritianum*	Wild tobacco		✔

Maroochy Research Station Vegetation Survey Area 1

Genus	Species	Common Name	FSB host	Exotic
Eucalyptus	*pilularis*	Blackbutt	?	
Eucalyptus	*intermedia*	Pink Bloodwood	?	
Eucalyptus	*microcorys*	Tallowood	?	
Cinnamomomum	*camphora*	Camphor Laurel		✔
Schefflera	*actinophyla*	Umbrella Tree	yes - *A. lutescens*	✔
Lophostemon	*conferta*	Brush Box		
Syncarpia	*glomuliferea*	Turpentine		
Hardenbergia	*violacea*	False sarsparilla		
Lomandra	*longifolia*	Mat Rush	yes - *A. lutescens*	
Hovea	*acutifolia*	Hovea		
Lantana	*camara*	Lantana		✔
Pteridium	*esculentum*	Bracken Fern		
Smilax	*australis*	Barbed Wire Vine		
Dianella	*caerulea*	Flax Lilly		
Geitonoplesium	*cymosum*	Scrambling Lilly		
Cryptocarya	*species*		yes - *A. nitida*	
Neolitsea	*dealbata*	Cycad		
Rubus	*molaccanes*	Wild Raspberry		
Pelidiostigma	*rhytispermum*	White Myrtle		
Polyscias	*elegans*	Celery Wood		
Culcita	*dubia*	Soft Fern		
Blechnum	*sp.*	Gristle Fern		
Acacia	*melanoxylon*	Black Wattle		
Elaeocarpus	*reticulatus*	Blueberry Ash	*yes - A. nitida*	
Glochidion	*sumatiranum*	Cheese Tree	*yes - A. lutescens*	
Macaranga	*tanarius*		*yes - A. lutescens*	
Clerodenron	*floribundum*	Lolly Bush		
Bambusa	*sp.*	Bamboo		✔

Maroochy Research Station Vegetation Survey Area 2

Genus	Species	Common Name	FSB host	Exotic
Solanum	*mauritianum*	Wild Tobacco		✔
Lophostemon	*confertus*	Brush Box		
Syncarpia	*glomulifera*	Turpentine		
Schefflera	*actinophylla*	Umbrella Tree	yes - A. lutescens	✔
Cinnamomum	*camphora*	Camphor Laurel		✔
Culcita	*dubia*	Soft Fern		
Glochidion	*sumatranum*	Cheese Tree	yes - A. lutescens	
Macaranga	*tanarius*		yes - A. lutescens	
Cryptocarya	*sp.*		yes - A. lutescens	
Eucalyptus	*pilularis*	Blackbutt	? suspected	
Alocasuarina	*torulosa*	Sheoak		
Desmodium	*triflorum*	Tick Trefoil		✔
Phylanthus	*sp.*			✔
Barna	*sp.*	Barna Grass		✔
Cissus	*antarctica*			
Eucalyptus	*intermedia*	Pink Bloodwood		
Elaeocarpus	*reticulatus*	Blueberry Ash	yes - A. nitida	
Alphitonia	*exelsa*	Red Ash/Soap Tree	yes - A. nitida, A. lutescens	
Eucalyptus	*microcorys*	Tallow Wood	? suspected	
Rubus	*molaccanes*	Wild Raspberry		
Ochna	*serrulata*	Mickey Mouse Plant		✔
Hovea	*acutifolia*	Hovea		
Jagera	*pseudorphus*	Foam-bark Tree		
Archontophoenix	*cunninghamiana*	Bangalow Palm	yes - A. lutescens	
Clerodenron	*floribundum*	Lolly Bush		
Parsonsia	*straminea*	Monkey Vine		
Polyscias	*elegans*	Celery Wood		
Imperata	*cylinorica*	Blady Grass		
Blechnum	sp.	Gristle Fern		
Desmodium	*triflorum*			✔

Appendix 3

Host records of some *Amblypelta* spp. from north-eastern Australia and neighbouring Pacific Islands

I	=	*Amblypelta nitida*	IV	=	*Amblypelta brevicornis*
II	=	*Amblypelta l. lutescens*	V	=	*Amblypelta cocophaga*
III	=	*Amblypelta l. papuensis*	VI	=	*Amblypelta theobromae*

+	=	record	min = minor	n	= Australian native host
F	=	feeding		x	= exotic host
B	=	breeding & feeding	maj = major	*	= new record

Host Plant	I	II	III	IV	V	VI	Reference
ACTINIDIACEAE							
Actinidia chinensis Planchon (x) (kiwi-fruit)	Fmin*						16*
ANACARDIACEAE							
Anacardium occidentale L. (x) (cashew nut)		Bmaj					13,16
Mangifera indica L. (x) (mango)	Bmaj	Bmaj	+		+		2,3,4,8,16
Pistachia vera L. (x) (pistachio)		Fmin*					16*
Schinus terebinthifolius Raddi (x)	Bmin*	Fmin*					16*
Spondias mombin L. (x) (yellow mombin)		Fmaj*					16*
ANNONACEAE							
Annona muricata L. (x) (soursop)		Fmaj*					16*
Annona reticulata L. (x) (custard apple)	Bmin	Bmaj					3,4,5,8,16
Rollinia sp.(x)		Bmaj*					16*
APOCYNACEAE							
Cryptostegia grandiflora (Roxb.) R. Br. (x) (Palay rubber vine)	+						2,3,5
Plumeria rubra L. (x) (frangipani)		Fmin	+				2,3,14,15,16
ARACEAE							
Anthurium sp. (x)		Fmin*					16*
Syngonium sp.		Bmin*					17*
ARALIACEAE							
Schefflera actinophylla (Endl.) Harms (n) (umbrella tree)		Fmin					7
Schefflera arboricola Hayata (x) (miniature umbrella tree)		Bmin*					16*

Host Plant	I	II	III	IV	V	VI	Reference
ARECACEAE							
Archontophoenix cunninghamiana (H.L. Wendl) Wendle&Drude) (n) (Bangalow palm)		Bmin*					16*
Cocos nucifera L. (x) coconut		Fmin	+		+	+	3,10,13,15
Livistona sp. (n) (cabbage palm)		Bmin*					16*
ASTERACEAE							
Lactuca sativa L. (x) (lettuce)		Bmin*					17*
Xanthium pungens Wallr. (x) (noogoora burr)		+					2,3,4,15
BOMBACACEAE							
Ceiba pentandra (L.) Gaertn. (kapok)					+		3
Durio zibethinus Murray (x) (durian)	Fmin*	Fmin*					16*
BROMELIACEAE							
Ananas comosus (L.) Merr. (x) (pineapple)		+					2,3
BURSERACEAE							
Canarium sp. L. (nali nut)					+		3,10
CAESALPINDACEAE							
Bauhinia galpinii N.E. Br. (x)	Bmin*	Bmaj					16*
Bauhinia variegata L. (x)	Bmin*	Bmin*					16*
Cassia fistula L. (x)		Fmin*					16*
Senna spectabilis (D.C.) Irwin & Barneby (x)		Fmin*					16*
Ceratonia siliqua L. (x) (carob)		Bmin*					16*
Delonix regia (Hook.) Raf. (x) quoted as (*Poinciana regia*)(flamboyant) by Phillips (1940) (poinciana)		Fmin*	Fmaj*		+		3,10,16*
Peltophorum pterocarpum (DC) K. Heyne (n) quoted as (*P. ferrugineum* (Decne.) Benth.) by Brimblecombe (1948)		+					2,15
CAPRIFOLIACEAE							
Vibernum suspensum Lindl (x)		Bmin*					16*
CARICACEAE							
Carica papaya L. (x) (papaw)	Bmin	Bmaj	+		+		2,3,4,5,14,16
Carica X (? *C. heilbronii* X *C. pentagona*) (x) (babaco)		Fmaj*					16*

Host Plant	I	II	III	IV	V	VI	Reference
CELASTRACEAE							
Denhamia celastroides (F. Muell.) Jessup (n)		Bmin*					16*
CLUSIACEAE							
Garcinia mangostana L. (x) (mangosteen)	Fmin*	Fmin*					16*
CONVOLVULACEAE							
Ipomoea batatas (L.) Lam. (x) (sweet potato)		Fmin*	+				15, 16*
Merremia pacifica V. Ooststr.					+		1
Merremia peltata (L.) Merr.					+		1
CUCURBITACEAE							
Citrullus sp (x) (water-melon sp.?)		Fmin*			+		3,16*
Cucumis melo L. (melon)					+		10
Sechium edule (Jacq.) Schwartz. (x) (choko)	+	Bmin*					16*, 4
wild cucumber		+					4
CYATHEACEAE							
Cyathea cooperi (Hook. ex F. Muell.) Domin (n) (tree fern)		Fmin*					16*
DIOSCOREACEAE							
Dioscorea sp. (yam)			+				18
EBENACEAE							
Diospyros virginiana L. (x) (persimmon)	Fmin*						16*
ELAEOCARPEACEAE							
Elaeocarpus grandis F. Muell. (n) (silver quandong)	Bmin*						16*
EUPHORBIACAE							
Codiaeum variegatum (L.) Blume		+			+		3,4,8,10
Croton sp. (x)		Fmin*					16*
Euphorbia pulcherrima Willd. quoted as (*Poinsettia pulcherimma*) by Phillips (1940)					+		3,10
Glochidion sp. Forster & Forster					+		5
Glochidion ferdinandi (Muell. Arg.) F.M. Bailey (n) (cheese tree)		Bmin*					16*
Hevea brasiliensis (A. Juss.) Muell. Arg. (rubber)			+			+	5,10,12,15
Homalanthus populneus (Giesel.) Pax quoted as (*Homalanthus populifolius* Graham) by Phillips (1940)					+		3
Jatropha curcas L.					+		3,10

Host Plant	I	II	III	IV	V	VI	Reference
EUPHORBIACEAE cont.							
Macaranga aleuritoides F. Muell.					+		1
Macaranga tanarius (L.) Muell. Arg. (n)		Fmin*			+		1,3,10,16*
Mallotus philippensis (Lam.) Muell. Arg. (n) (red kamala)	Fmin*	Bmin*					16*
Manihot esculenta Crantz (x) (cassava)		Fmin	+		+	+	6,8,10,15,16
Pedilanthus tithymaloides (L.) Poit. (x) (zigzag plant)		Bmin					14
Ricinis communis L. (x) (castor bean)		Bmaj*					16*
FABACEAE							
Erythrina crista-galli L. (x) (coral tree)		Bmin*					16*
Glycine max (L.) Merrill (x) (soybean)		+					14
Phaseolus atropurpureus D.C. (x) (Siratro)	Bmin*	Bmin*					16*
Psophocarpus tetragonolobus (L.) DC (winged bean)			+		+	+	7
Vigna radiata (L.) R. Wilczek (mung bean)			+				3,15
Vigna unguiculata sesquipedalis (L.) Verdc. (snake bean)			+				18
Vigna unguiculata (L.) Walp. (cowpea)					+		3
IRIDACEAE							
Iris spp. (x) (iris)		Fmin*					16*
JUGLANDACEAE							
Carya illinoensis (Wagenh.) C.Koch (x) (pecan nut)	Fmin	Fmin*					4,5,8,16*
LAURACEAE							
Actinodaphne solomonensis C.K. Allen				+		4,5,8	
Persea americana Mill. (x) (avocado)	Bmaj	Bmaj*				4,5,8,16*	
Cryptocarya leavigata Blume (n) (red-fruited laurel)		Fmin*					16*
LECYTHIDACEAE							
Barringtonia edulis Seem.					+		3
LEEACEAE							
Leea indica (Burm. f.) Merr. quoted as (*Leea sambucina*) by Phillips (1940)					+		3,10
LILIACEAE							
Gloriosa superba L. (x) (glory lily)		Fmin*					16*

Host Plant	I	II	III	IV	V	VI	Reference
MAGNOLIACEAE							
Michelia champaca (x) (champak)	Bmin*	Bmin*					16*
MALPHIGIACEAE							
Malpighia punctifolia L. (x) (acerola)	Bmin*						16*
MALVACEAE							
Abelmoschus manihot (L.) Medicus (aibika)			+				18
Gossypium sp. (x) (cotton)		+					2,3,4
Hibiscus sp. (x) (Hawaiian hibiscus)		Fmin*					16*
Hibiscus tiliaceus L. (n) (cotton tree)		Bmaj*					16*
Urena lobata L. (urena burr)			+				3,4
MELASTOMACEAE							
Melastoma malabathricum L.					+		3
MELIACEAE							
Amoora sp.					+		3
Dysoxylum sp.					+		3,10
Melia dubia Cav. (white cedar)		+					3,15
Melia azedarach L. (x) (white cedar)	Bmin*	Bmaj					5,16*
MENISPERMACEAE							
Stephania sp. (n)	Bmaj*	Bmaj*					16*
MIMOSACEAE							
Calliandra sp. (n)	Bmin*	Bmin*					16*, 17*
MORACEAE							
Artocarpus communis Foster & Foster (breadfruit)			+				18
Artocarpus heterophyllus Lam. (jack-fruit)	Fmin*	Fmin*					16*
Ficus carica L. (x) (common fig)	Bmin*	+			+		1,3,10,15,16*
Ficus copiosa Steud.					+		3
Ficus leucotricha Miq. (n) (rock fig)		+					14
Ficus racemosa L. (n) (rough-leafed fig)	Bmin*	Bmin					5,16*
Ficus septica Burm. quoted as (*Ficus leucantotoma*) by Phillips (1940)					+		3
Morus nigra L. (x) mulberry)	Bmin*	Bmin					4,8,16*

Host Plant	I	II	III	IV	V	VI	Reference
MUSACEAE							
Musa paradisiaca L. (x) (banana)		Bmin					2,3,4,14,16
MYRTACEAE							
Eucalyptus deglupta Blume					+		1,9
Eucalyptus camaldulensis Dehnh. (n) (river gum)		+					14
Feijoa sp. (x) (feijoa)	Bmin*						16*
Melaleuca sp. (tea tree)				+			4,8
Myrciaria cauliflora (DC) Berg (x) (jaboticaba)	Bmin*						16*
Psidium gaujava L. (x) (guava)	Bmaj	Bmaj	+				4,5,8,14,16
Psidium cattelianum Sabine (cherry guava)	+						4
Syzigium spp.	Bmin*	Bmin*					16*
NYCTAGINACEAE							
Calpidia brunoniana (Endl.) Heimerl quoted as (*Pisonia brunoniana*) (n) by Brimblecombe (1948)		+					2,3,15
OLEACEAE							
Olea europaea L. (olive)				+			4,8
ORCHIDACEAE							
Dendrobium spp. (x) (dendrobium orchids)		Fmin*					16*
OXALIDACEAE							
Averrhoa carambola L. (x) (carambola)	Bmin*	Bmaj*					16*
PANDANACEAE							
Sararanga sp.					+		3
PASSIFLORACEAE							
Passiflora edulis Sims. (x) (passion fruit)	Bmin	Bmin*					2,3,15,16*
Passiflora quadrangularis L. (x) (grenadilla)	+	Bmin*			+		2,3,15,16*
Passiflora suberosa L. (x) (corky passion flower)	Bmaj*	Bmaj					2,3,5,15,16*
Passiflora subpeltata Ortega (white passion flower)		+					2,3,15
PIPERACEAE							
Piper nigrum L. (x) (pepper)		Fmin*					17*

Host Plant	I	II	III	IV	V	VI	Reference
PITTOSPORACEAE							
Pittosporum rhombifolium A. Cunn. Ex Hook. (n) (diamond laurel)		Fmin*					16*
POACEAE							
Saccharum officinarum L. (sugar cane)					+		3
POLYPODIACEAE							
Hypolepis tenuifolia (Forst. f.) Bernh.					+		3
PROTEACEAE							
Macadamia integrifolia Maiden & Betche (n) (macadamia nut)	Bmaj	Bmaj					2,3,4,5,8,16
Macadamia tetraphylla L.A.S. Johnson) (n) (macadamia nut)	Bmaj	Bmaj					5,16
PUNICACEAE							
Punica granatum L. (x) (pomegranate)		Bmin*					16*
RHAMNACEAE							
Alphitonia excelsa (Frenzl.) Benth. (n) (soap bush)		Fmin					14
Alphitonia petrei Braid and White (n) (soap bush)	Bmaj*	Bmaj*					16*
ROSACEAE							
Eriobotrya japonica (Thunb.) Lindley (x) (loquat)	Bmaj*	Bmaj*					16*
Fragaria x ananassa Duch. (x) (strawberry)	Bmin*						16*
Malus sylvestris Mill. (x) (apple)	+						4,5,8
Prunus domestica L. (x) (plum)	+	+					3,5
Prunus persica vulgaris (L.) Batsch. (x) (peach)	Fmin	Bmin*					3,4,5,16*
Prunus persica var. nectarina (x) (nectarine)	+	+					3,5
ROSACEAE							
Rhaphiolepis indica (L.) Lindl (x) (Indian hawthorn)	Bmin*						16*
Rosa spp. L.(x) (rose)		Bmin*					16*
Rubus indaeus L. (x) (raspberry)	Bmin*						16*
Rubus mollucanus L.					+		1
RUBIACEAE							
Coffea araca L.(x) (coffee)		Fmin*					16*
Ixora chinensis (x)		B.min*					16*

Host Plant	I	II	III	IV	V	VI	Reference
RUTACEAE							
Casimiroa edulis Llave & Lex. (x) (white sapote)	Bmaj*	Bmin*					16*
Citrus mayeri Y.Tan. (x) (Meyer lemon)		Bmin*					16*
Citrus reticulata Blanco (x) (Imperial mandarine)	Fmin*	Fmin*					16*
Citrus sinensis (L.) Osbeck (x) (late valencia orange)	Fmin*	Fmin*			+		10,16*
Citrus sinensis varr. (x) (Navel orange)		Fmin*					16*
Clausena brevistyla Oliver (n)	Bmin*	Bmin*					16*
Erimocitrus glauca (Lindl.) (n)	Bmin*						16*
Fortunella margarita (lour.) Swing. (x) (kumquat)		+					4
Geijera parviflora Lindl. (wilga)				+			4,8
Murraya paniculata (L.) Jack. (x) (orange jessamine or mock orange)	Bmaj*	Bmaj*					16
SAPINDACEAE							
Alectryon coriaceus (Benth.) Radlk (n) (beach bird's eye)		Bmaj*					16*
Cupaniopsis sp.					+		3
C. anacardioides (A. Rich.) Radlk. (n) (tuckeroo)		Bmin*					16*
Dimocarpus longan Lour. (x) (longan)	Bmaj*	Bmaj*					16*
Guioia semiglauca (F. Muell.) Radlk. (x)	+	+					2,3,5,15
Litchi chinensis Sonn. (x) (lychee)	Bmaj*	Bmaj*					16*
Nephelium lappaceum L. (x) (rambutan)		Fmin*					16*
SAPOTACEAE							
Manilkara zapota (L.) van Royen (x) (sapodilla)		Fmin*					17*
Planchonella pohlmanniana (F. Muell.) Pierre ex Dubard (n) (yellow boxwood)		+					3,4
SOLANACEAE							
Capsicum sp. (red chilli)					+		3,10
Cyphomandra crassicaulis (Ortega) Kuntze (x) (tamarillo)		Fmin*					17*
STERCULIACEAE							
Ambroma augusta (L.) L. f. (devils cotton)			+				15
Theobroma cacao L. (x) (cocoa)		Fmin*	+		+	+	3,6,8,11,17*
THEACEAE							
Camellia japonica L. (x) (camellia)		Bmin*					16*

Host Plant	I	II	III	IV	V	VI	Reference
TILIACEAE							
Grewia asiatica L. (x)	Bmin*	Bmin*					16*
Triumfetta rhomboidea Jacq. quoted as (*Triumfetta bartrami*) by Phillips (1940)					+		3
URTICACEAE							
Pipturus argenteus (G. Forst.) Wedd.					+		1
VERBENACEAE							
Clerodendrum sp.					+		1
VITIACEAE							
Vitis vinifera L. (x) (grape)	Bmin*	Bmin*			+		10,16*
XANTHORRHOEACEAE							
Xanthorrhoea sp. (n) (grass tree)	+						4
Lomandra longifolia Labill. (n)		Bmaj*					16*
ZINGIBERACEAE							
Alpinia sp. (n) (wild ginger)		Fmin*					16*

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