MONITORING THE BROWN WATTLE MIRID,

LYGIDOLON LAEVIGATUM

(Hemiptera: Miridae)

by

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PREFACE

This study was completed at the Institute for Commercial Forestry Research (ICFR). The author was registered with the Department of Zoology and Entomology, University of Natal, Pietermaritzburg from February 1994 to December 1995. Professor Michael J. Samways supervised the work.

These studies represent original work by the author and have not been submitted in any form to another university. Where use was made of the work of others, it has been duly acknowledged in the text.

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CHAPTER 1

AN INTRODUCTION TO THE BROWN WATTLE MIRID *LYGIDOLON LAEVIGATUM*

1.1 THE INSECT

ORDER: Hemiptera

SUBORDER: Heteroptera

SUPERFAMILY: Cimicomorpha

FAMILY: Miridae

SUBFAMILY: Mirinae

TRIBE: Mirini Hahn 1831

GENUS: *Lygidolon* Reuter 1907

SPECIES: *laevigatum* Reuter 1907

COMMON NAME: 'brown wattle mirid', more often shortened to 'the wattle mirid'

(From: Connell 1970)

The brown wattle mirid was first described by Reuter in 1907, but has since been redescribed by Odhiambo (1960) and Connell (1970). The family Miridae is the largest family of the Heteroptera in the world (Scholtz & Holm 1985). The Miridae is usually divided into six subfamilies, all of which are represented in South Africa (Scholtz & Holm 1985). The southern African mirid fauna is very poorly known and less than a quarter of the estimated 1000 species (belonging to about 250 genera) are described (Scholtz & Holm 1985).

Adult wattle mirids are black or chestnut in colour, with a yellow triangular scutellum. The adult females differ slightly in colour from the males; with the females having a chestnut-coloured pronotum (Plate 1a) and the males having a more black pronotum and a less well-pronounced scutellum (Plate 1b). The adults are small, with females being, on average 3.37 mm long and males 3.19 mm long (Connell 1970).

There are five nymphal instars (Fig. 1). The nymphs are green, with a hemimetabolous development typical of exopterygotes (Davies 1988). Time of development from first nymphal instar to adult varies, but averages 14 days early in the season (January to February) and 18 days as the temperature drops (April to June) (Connell 1970). The nymphs are fairly active and will move from tree to tree when they are touching (Connell 1970). The nymphs and adults feed on the tender growing tips of young black wattle trees (*Acacia mearnsii* de Wild). Connell (1970) also found *L. laevigatum* on a variety of other plants, including: two species of Compositae (*Tagetes minuata* L. and *Crassocephalum crepidioides* Benth.), one species of Phytolaccaceae (*Phytolacca octandra* L.), and, two indigenous species of *Acacia* (*Acacia nilotica* (L.) and *A. karroo* (L.)). The insect occurs throughout the wattle-growing areas of southern Africa.

The female wattle mirid lays eggs in the tender young growth of actively flushing young wattle trees. The eggs are often inserted between the pinnae of tiny developing leaves, or within the apical bud (Connell 1970). Eggs are normally laid singly and are often close together (Connell 1970). The position of the eggs in the apical region gives the nymphs easy access to the young developing shoots and buds. The eggs hatch after about 7 days early in the season (January), but take about 12 days in June (Connell 1970).

Plate 1a: Adult female wattle mirid

Plate 1b: Adult male wattle mirid

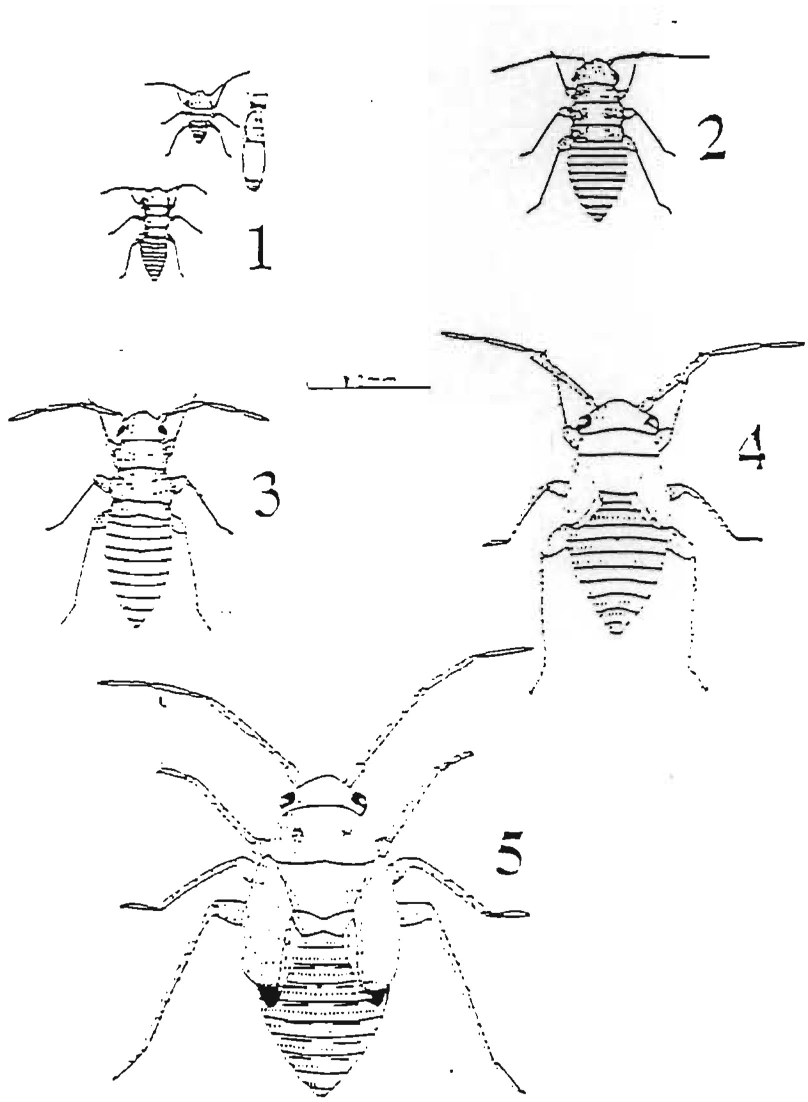

Figure 1: The five nymphal instars of *Lygidolon laevigatum* (Reproduced with permission from Connell 1970)

1.2 TYPE OF DAMAGE CAUSED

Hemiptera are restricted in their feeding behaviour by the nature of their mouthparts: they are only able to swallow liquids and particles in suspension (Dolling 1991). The internal tissues of leaves and stems are easily penetrated by inserting the stylets from the outside (Dolling 1991). *Lygidolon laevigatum* feeds by piercing the tissue of the host plant. To ensure the flow of sap, the wattle mirid injects a toxic saliva into the feeding puncture (Connell 1970). The saliva kills the tissue within the feeding puncture, which then becomes shrivelled and forms dark red-brown spots on the leaves (Connell 1970). Both adults and nymphs feed on the pinnules of young, or developing leaves, the tissues of tiny developing leaves, and sometimes the meristematic tissue of terminal buds (Govender & Fletcher 1994).

Earlier this century, foliage damage to *A. mearnsii* was reported to be caused by a group of small mobile Heteroptera species, referred to collectively as 'froghoppers' (Anonymous 1926). This group included the caspids (now Miridae), Cicadellidae and a number of other suspected pests (Anonymous 1926). However, Connell (1970), discovered that *L. laevigatum* was the only species to be seriously implicated in damage. The 'froghopper' was first identified as *L. laevigatum* in August 1929 (Anonymous 1929), and the damage caused by the insect (crooked timber and the 'witches broom' effect) was illustrated (Anonymous 1929).

L. laevigatum causes severe damage to young wattle trees, usually those between 0.3 m and 5.0 m in height (Govender & Fletcher 1994). The damage can be assigned to four broad categories:

1.2.1 Pinnule feeding (Plate 2a)

The puncture caused by the penetration of the mouth-parts leaves a small dark-red spot on the pinnule. If the feeding has occurred near the edge of the pinnule, the pinnule becomes bent. The nymphs may feed on a single leaf for several days, resulting in a large percentage of the pinnules having puncture marks. This gives the leaves a ragged appearance, in comparison to undamaged pinnules.

1.2.2 Feeding on the apical bud (Plate 2b)

These lesions are larger than those caused by pinnule feeding. The stylets often penetrate the rachis of the leaf which becomes distorted. When the stylets penetrate the apical bud, it dies.

1.2.3 Multiple branching (Plate 2c)

When the apical bud is destroyed, the source of the growth-inhibiting hormone is removed (Connell 1970). This results in several side shoots in the leaf axils below the apical bud. These axils then become the dominant leader shoots, resulting in forking.

1.2.4 Witches broom effect and pinnule loss (Plate 2d)

With the continued presence of the wattle mirid, the new leader shoots are also destroyed and further shoots develop and, in turn, are destroyed. This continued sprouting and destruction of the shoots results in excessive multiple branching and a type of 'witches' broom'. Severe damage also results in abnormal pinnule loss, and the bark of the tree may turn a greyish-black colour. At this stage, the wattle mirids leave the tree.

Plate 2a: Damage to pinnules of black wattle, caused by feeding of *L. laevigatum*

Plate 2b: Damage to apical bud of black wattle, caused by feeding of *L. laevigatum*

Plate 2c: Multiple branching of black wattle tree, caused by feeding of *L. laevigatum*

Plate 2d: 'Witches broom' effect, caused by feeding of *L. laevigatum*

1.3 ECONOMIC IMPORTANCE OF BLACK WATTLE

In South Africa there are about 1.33 million hectares of exotic commercial forestry plantations, the total of which comprises about 1.2% of the total area of land in the country (Department of Water Affairs and Forestry 1993). In turn, about 106 000 hectares are planted to black wattle. The Kwazulu-Natal midlands have the greatest concentration of black wattle (43%) (Department of Water Affairs and Forestry 1993).

Wattle has become an important plantation tree, as there is an increasing demand for its bark extracts for tanning, resins and adhesives (Atkinson 1993). As a source of tannin, it shares with quebracho and chestnut, the major portion of the world market for vegetable tans (Sherry 1971). Wattle is grown for both its bark and its timber for mine poles (Department of Water Affairs and Forestry 1993). If the timber is crooked, then it is marketed as firewood or for conversion to charcoal (Department of Water affairs and Forestry 1993). It is also used for certain paper products. Its relative availability and dense wood for pulping outweigh the problems of milling (Atkinson 1993). The wattle is also tolerant of drought conditions and will grow in poor shallow soils (Borthwick 1990). It is recognised as one of the best forestry options for inland marginal forestry sites where it grows faster than pine species (Govender 1994). Wattle plantations are hardy and more fire resistant when compared with the *Eucalyptus* and *Pinus* plantations (Atkinson 1993).

During the 1993/94 season, a total of 7078 ha of black wattle was reported to be damaged by *L. laevigatum* (Govender 1994). Severe attacks from the wattle mirid affect the form of the tree and result in a loss of growth. This, in turn, reduces bark and timber yields (Atkinson & de Laborde 1993). The damage requires corrective pruning, which is labour-intensive and costly.

1.4 CONTROL OF *LYGIDOLON LAEVIGATUM*

Control measures should be applied early in the season when the wattle mirid population is still increasing, and not at its peak, in late summer, when the damage is already done. However, a major problem is that *L. laevigatum* populations are not detected until late in the season when the damage becomes visible (Atkinson 1993).

1.4.1 Biological control

Most of the forestry pests in South Africa are indigenous and are not amenable to classical biological control (Atkinson & de Laborde 1993). The wattle mirid is also an indigenous pest and has been collected from local species of *Acacia* (Connell 1970). This fact, and its rapid breeding, mean sufficiently effective biological control is unlikely.

Some species which occur in black wattle plantations and may prey on the wattle mirid, are ladybirds (Coccinellidae), lacewings (Chrysopidae), spiders (Araneae), adult and juvenile praying mantids (Mantidae), rove beetles (Staphylinidae) and robber flies (Asilidae) (Connell 1970; Govender 1995). Important parasitoids of the nymphal stages of the wattle mirid include *Euphorus nigricarpus* Szeligeti and *Euphorus praetor* Nixon, both of which are braconid wasps (Connell 1970). Other parasitic wasps that may control the wattle mirid include species from the Ichneumonidae, Braconidae, Chalcididae, Trichogrammatidae and Sceilionidae (Govender 1995). Connell (1970) found that the percentage parasitism in isolated plantations was between 20 and 30 percent. These levels of parasitism were insufficient to exert effective biological control. However, when a plantation was attacked for two successive seasons, the percentage parasitism increased to between 60 and 70 percent (Connell 1970), and although some damage was present, this high percentage appeared to be sufficient to prevent extensive damage (Connell 1970).

Majer (1972) suggested that ants of the genera *Crematogaster* and *Oecophylla* (Formicidae) warrant investigation as biological control agents of the wattle mirid on black wattle, and both are found in South Africa (Scholtz & Holm 1985). Other ants which have been exploited as control agents overseas, include *Oecophylla longinoda* (Latreille) on cocoa in West Africa (Way & Khoo 1991; Azhar 1989), and *Solenopsis invicta* Buren on cotton in Texas (Breen *et al.* 1990). These two genera are also found in South Africa, although the *Solenopsis* species in South Africa is different from the new world one (Scholtz & Holm 1985).

Although it has been suggested (Majer 1972) that ants may play an important role in the control of mirids they are for the most part, polyphagous, and as such are not considered ideal candidates for biological control (Dent 1991). There are a number of other problems associated with ants as biocontrol agents: beneficial ant species are often displaced by other competing dominant pest ant species (Way & Khoo 1991); some beneficial ant species also depend on a reliable year-round food source from honeydew-producing Homoptera, especially certain pseudococcids, coccids and aphids. This means that they have the potential to increase these pests by interfering with the natural enemies of the honeydew-producing Homoptera (Way & Khoo 1991, Stehr 1975). Therefore, on balance, biological control of the wattle mirid using ants does not appear to be feasible.

1.4.2 Chemical control

The economic loss per hectare if black wattle is left untreated is estimated to be approximately R809 (Atkinson & de Laborde 1993). Yet there are no insecticides registered for chemical control of *L. laevigatum* (Govender 1994). However, the relatively low economic threshold population (6-10 adults per tree (Connell 1970)), and rapid lifecycle mean, out of desperation, that chemical pesticides are often illegally applied.

Currently, the wattle mirid is controlled on a corrective basis when the damage is noticed. The pesticide used for the control of *L. laevigatum* in forestry is monocrotophos, applied aerially at a concentration of about 80 to 200 g a.i.ha^{-1}, and at a cost of between R 35 and R 45 per hectare (Atkinson & de Laborde 1993). Treatment of heavily infested areas during 1993/94 was estimated to cost approximately R 124 500 (Govender 1994). Monocrotophos is extremely toxic, with a LD_{50} of 8mg.kg^{-1} (Thomson 1992). Attempts to register monocrotophos for use against the wattle mirid have been unsuccessful, because of the toxic nature of the chemical (Govender 1994).

Alternative chemical treatments are being screened. Govender (1994, 1995) tested the effectiveness of a number of different pesticides and application methods on the wattle mirid in order to find an effective yet ecologically acceptable pesticide. Application of the pesticide is with knapsack sprayers (Govender 1994, 1995). Pesticides tested included deltamethrin, acephate and methamidophos (Govender 1994, 1995).

The most economically-promising pesticide is the synthetic pyrethroid, deltamethrin because of the effective very low concentration (0.003g per tree) (Govender 1994). Deltamethrin is, however, a broad spectrum insecticide, resulting in the numbers of natural enemies being severely reduced (Govender 1994, 1995). Acephate has a contact and systemic mode of action. It was found to be a promising insecticide for use against localised outbreaks of populations of wattle mirid nymphs (Govender 1995).

In view of the various predators and parasitoids active in the population, it is desirable to use a systemic insecticide which beneficially alters the natural-enemy/host balance and can be used in ecologically sensitive areas. Generally, these systemic insecticides kill the sap-sucking insects which feed on the treated crop, and do not affect the natural enemies (Govender 1994, 1995). In this regard, the systemic insecticide methamidophos showed the most promise for the control of *L. laevigatum* (Govender 1994, 1995).

1.4.3 Integrated Pest Management (IPM)

Greater emphasis now needs to be placed on integrated pest management (IPM). Over reliance on chemical pesticides has been shown to be environmentally and economically unsound (Azhar 1989). Unexpected problems such as outbreaks of secondary pests may appear, as a result of the destruction of natural enemies and ecosystem imbalances, following inappropriate chemical applications (Samways 1981, Azhar 1989). Chemical pesticides unquestionably play an important role in the management of wattle mirids, but they have to be harmoniously incorporated into an IPM system, to ensure maximum economic benefits with minimum environmental impact.

The major feature of IPM is minimal use of synthetic pesticides and maximum reliance on natural regulatory mechanisms to maintain pests below the level at which they cause economic damage (Perfect 1992). IPM should not be viewed as an alternative to chemical, biological, or cultural control, it represents a combination of all methods, aiming to be cost-effective, durable, and environmentally friendly (Whitten 1992).

IPM involves regular monitoring to ensure that pesticides are applied less often and at the correct time, thus increasing effectiveness with a reduction in the cost of chemicals and a decrease in environmental damage (Azhar 1989, Pfadt 1985). It also involves the utilisation of natural enemies in the habitat to regulate pest numbers through predation and parasitism (Azhar 1989).

IPM systems have been successfully employed against mirid populations in tea plantations in India, where biological control alone was unable to maintain mirid populations below the economic threshold (Stonedahl 1991). Integrated control programmes with reduced pesticide use and the monitoring of natural enemies were suggested as reasonable alternatives to blanket spraying with chemical pesticides (Stonedahl 1991). Spot treatments, as proposed by Azhar *et al.* (1983) for the treatment of mirids on cocoa plants, is a method by which natural enemies can be preserved in edge habitats.

An easy and effective monitoring system for *L. laevigatum* in wattle would provide foresters with the data which could facilitate the implementation of spot treatments with registered pesticides. In terms of aerial spraying, where approximately seven rows of trees are sprayed at a time (Govender 1994), specific spot treatments are not possible. However, application of finer grained treatments, using ground-based methods or microlight aircrafts, allows for more specific spot treatments.

1.5 POPULATION MONITORING

Population monitoring is used to forecast pest outbreaks (Conway 1984). Such forecasts are important in pest management, because a warning of the timing, and extent, of pest attack can improve the efficiency of control measures and reduce the use of pesticides (Dent 1991). The appropriate timing of an insecticide application may depend solely on detecting, or predicting, the presence of the insect pest that causes the economic damage (Dent 1991). Population surveys and thresholds for insecticide applications have been used successfully within many IPM programmes, including control of soybean pests in Brazil (Moscardi & Ferreira 1985) and control of Cassava mealybug in Africa (Van Alphen *et al.* 1989).

There is a need for researchers to overcome the problems farmers face in population assessment (Perfect 1992). Monitoring of field populations is a necessary part of forecasting, and monitoring of changes in pest populations is essential for effective management (Pedgley 1982).

Monitoring is often achieved through trapping of pest species (Pedgley 1982). Insect traps can be used at a simple level for the assessment of pest activity, and population levels, which allows appropriate control measures to be taken (Perfect 1992). Trap estimates may reflect regional population changes, and be used to forecast levels of field infestations, and provide an early warning to foresters for spraying (Dent 1991).

In the absence of a forecasting or monitoring system a forester would either apply an insecticide regardless of the level of pest attack (prophylaxis), or not apply an insecticide at all (Dent 1991). The "no control" option would mean that in non-outbreak years, the forester would maximise his profits, but in outbreak years total yield and monetary loss may occur (Dent 1991). The "prophylaxis" option in non-outbreak years, would result in a loss of profit due to the unnecessary use of insecticides, and in outbreak years the forester would control the pest, but he may use too many (or too few) insecticide applications for effective control (Dent 1991). The common factor in both strategies that influences the foresters profit is the probability of an outbreak, and the severity of attack by the pest (Dent 1991). A monitoring and forecasting system that correctly predicts outbreaks of the pest would greatly improve profits and would also have ecological and environmental benefits.

1.6 AIMS AND RATIONALE FOR THE STUDY

Foresters tend to notice the presence of the wattle mirid through the damage it causes rather than through any quantitative counts of the insect. By this stage, however, it is too late to prevent further damage. Therefore, it is of vital importance to develop a monitoring technique which is simple, effective and easy to use, and which will provide the forester with early indications of infestation and signal action against economic losses. Indeed, forestry is a long-term capital crop that would greatly benefit from an inexpensive, practical and effective monitoring method that protects the crop throughout its growth.

In the past, most of the work has been confined to investigation of control measures, with the wattle industry paying little attention to the development of monitoring techniques. In 1993, the wattle industry recognised the need for a practical monitoring technique. It requested the development of such a technique that could be incorporated into an integrated management system, and which would reduce the use of illegal pesticides. An initial pilot study involving trapping of *L. laevigatum* (Atkinson & Stewart 1993), was carried out for three months.

This study was a large-scale reassessment, refinement and development of the pilot work. It results in the development of a simple, effective monitoring technique for the wattle mirid.

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CHAPTER 2

CHOICE OF TRAPPING TECHNIQUE

SUMMARY

The aim here was to select an effective monitoring apparatus that would warn the forester of an impending outbreak of the brown wattle mirid, *Lygidolon laevigatum*. Three instantaneous collecting methods were tested; 1) sweep net, 2) beating tray, and, 3) D-vac machine. The sweep net was effective for assessing numbers of adults, and the beating tray that of nymphs. The D-vac machine was not effective for either life stage. Such instantaneous methods are not feasible for use by the forester, so more cost-effective cumulative trapping methods were then tested. Three types of such cumulative traps were screened; 1) commercially available citrus trap, 2) sticky board, and, 3) cylindrical plastic 'Coke' bottle. Of the cumulative traps, the 'Coke' bottle trap was the best, being simple, effective and reliable.

2.1 INTRODUCTION

Monitoring of *Lygidolon laevigatum* will provide the forester with an early warning system enabling action to be taken before the pest exceeds the economic threshold. The choice of sampling method should maximise precision while minimising sampling time and sampling costs (Schotzko & O'Keeffe 1986).

Ecological studies often require estimates of absolute densities (numbers per unit area or volume). These studies also form the basis for the development of integrated pest management strategies (Fleischer *et al.* 1985). However, the time and effort needed to accurately estimate absolute densities is often excessive (Schotzko & O'Keeffe 1986), and, in response, management decisions are frequently based on rapidly-obtained relative density estimates (Fleischer *et al.* 1985).

Relative methods can be lumped into two broad categories, 1) catch per unit effort, and 2) trapping (Ruesink & Kogan 1975). The first category includes active, or instantaneous methods, such as, the sweep net, the D-vac machine, and the beating tray (Ruesink & Kogan 1975). The second includes passive, or cumulative methods, such as sticky traps (Ruesink & Kogan 1975).

Absolute methods can be defined as a count of insect numbers with reference to a predefined unit measure (Dent 1991), for example, number of insects per unit of habitat (Southwood 1978). Absolute estimates are measures of the actual insect density and are directly comparable in space and time (Dent 1991). Quadrats and emergence cages are examples of absolute measures (Dent 1991). Other approaches to measuring absolute population densities include 1) distance to nearest neighbour, 2) sampling a unit of habitat, 3) recapture of marked individuals, and, 4) removal trapping (Ruesink & Kogan 1975, Southwood 1978).

Relative methods have one distinct advantage over absolute methods, a given amount of labour and equipment yields much more data, and if wisely chosen can capture up to 100 times as many insects as an absolute method (Ruesink & Kogan 1975). On statistical grounds, this is often the reason why a relative method is preferred over an absolute one (Ruesink & Kogan 1975). Relative estimates can sample the mobile aerial population of pest species, in this way relative estimates have potential use in early warning of crop infestation, and for this reason the use of relative estimates has been popular in pest management research programmes (Dent 1991).

Hemiptera occupy a wide range of habitats and, therefore, require varied collecting methods (McGavin 1993). Not all trapping techniques are particularly useful for Hemiptera, for instance Malaise traps, and other flight interception traps, are not as effective in catching Hemiptera, as they are for other insect groups (Dolling 1991, McGavin 1993). Many mass collection techniques, such as light trapping or insecticidal knockdown, may catch large numbers of Hemiptera (Hodkinson & Casson 1991), but can only provide presence or absence data (McGavin 1993), and cannot be used for collecting host-specific Hemiptera (Hodkinson & Casson 1991). Pitfall traps sometimes capture bugs, but not in sufficient numbers to make it worthwhile using them specifically for this group (Dolling 1991). Powerful suction devices that continuously sample large volumes of air and direct airborne insects into a collecting jar of alcohol, are too cumbersome and expensive for the casual user, but are often used professionally to sample flying aphids (Dolling 1991).

Coloured pan traps are often used by hemipterists (Dolling 1991). They consist of coloured trays of water containing a surface tension-reducing substance, such as washing up liquid. Certain colours, principally yellow, attract aphids and other Hemiptera (Dolling 1991). The disadvantage with this type of trap is that it requires regular inspection. During hot weather, the water rapidly evaporates, and during rain, the tray may overflow and the insects be lost

(McGavin 1993). Another disadvantage is that they can only be used in places where disturbance by humans and animals is minimal (McGavin 1993).

Preliminary work by Atkinson and Stewart (1993), tested various types of sticky traps and the use of the sweep net for sampling of *L. laevigatum*. The aim here was to continue, expand and develop this work so as to find the most efficient, the cheapest and the easiest method of capture for *L. laevigatum*, testing various types of relative sampling techniques.

2.2 STUDY SITES

Commercial plantations were used, four of these were selected for the study. Three of the four sites were in the Umvoti area, at the Sappi plantation, "Greenpoint" (29°13'S 30°35'E; elevation 1113 m). The fourth site was at the "Bloemendal" Experiment Station, about 14 km North East of Pietermaritzburg (29°32'S 30°28'E; elevation 860 m). These sites were chosen on the basis of their infestation level at the start of the experiment. Connell (1970) stated that between 6 and 10 adult wattle mirids per tree was a high infestation, and on this basis, three infestation levels were chosen. Site one had a 'low' infestation, with about one adult wattle mirid per tree, Site two had a 'medium' infestation with about four adults per tree, and, Site three had a 'high' infestation with eight adults per tree.

The fourth site was chosen in case any of the other sites had to be sprayed by the forester with insecticide during the experiment. This site had a 'medium' infestation, with four adult wattle mirids per tree.

2.3 MATERIALS AND METHODS

All were based on a randomised design (Ludwig & Reynolds 1988), which is useful when the experimental plots are homogeneous, i.e. the variation among them is small (Steel & Torrie 1981).

Two different types of relative sampling techniques were used: 1) instantaneous sampling, and 2) cumulative trapping.

The sampling methods were used at all of the sites and each method was replicated six times at each of the sites, i.e. 36 trial plots per site. Sites were sampled mostly every 14 days. The experiment ran from March 1994 to September 1994.

2.3.1 Instantaneous sampling methods

These sampling methods are from the first category of relative population density estimates (i.e. catch per unit effort), and require active sampling. The techniques used were a D-vac machine, a beating tray and a sweep net.

Sweep net samples were taken from six trees within the plot, with each tree being swept six times. The same technique was used for both the beating tray and the D-vac machine, each time six sub-samples were collected from six trees within the plot. The resulting samples were stored in 70% ethyl alcohol and taken back to the laboratory, where they were sorted and separated into the different life stages.

2.3.1.1 Suction apparatus (the D-vac machine)

Various suction machines have been devised to obtain estimates of the relative densities of various arthropod populations living in vegetation. Southwood (1978) mentions 10 such devices, but the wide hose model (the 'D-vac') developed by Dietrick (1961), is probably the most familiar and commonly used machine (Summers *et al.* 1984). This model is particularly suited for use with animals on herbage (Southwood 1978). The advantage of this system is that sampling from different areas can be standardised and is relatively objective (Summers *et al.* 1984).

The D-vac has been widely used to sample predacious arthropods on apple trees (Lord 1965); leafhoppers on cherry trees (Purcell & Elkinton 1980), and thrips on citrus (Grout *et al.* 1986).

The D-vac machine used in this experiment ran off a small 50cc petrol motor, which drove a Squirrel-cage type of fan and produced a strong air current (Plate 3). The fan was attached to a wide canvas hose. The D-vac overcame the problem of insects adhering to the hose by having the collecting bag incorporated in the widened nozzle. The insects were collected from the surface of the tree when the apex of the hose was passed across the branch.

Initial analysis showed significant differences between the trapping methods. As the D-vac machine produced poor results it was discarded from the experiment in June 1994.

2.3.1.2 Beating tray

Beating has been used extensively in the past and involved hitting the tree sharply with a stick and collecting the insects in an umbrella held upside down under the tree (Southwood 1978). The umbrella has been replaced by a beating tray (Southwood 1978). Design of the tray differs greatly, but the background colour of the tray should contrast with the type of insects being collected (Southwood 1978).

Beating trays have been widely used for the capture of phytophagous Hemiptera. Fleischer *et al.* (1985) found the beating tray provided an accurate relative estimation of the population of *Lygus lineolaris* (Palisot de Beauvois) on cotton. A study by Herms *et al.* (1990) also found that the beating tray provided an accurate estimate of the phenology of five phytophagous species of Hemiptera on mature honeylocust (*Gleditsia triacanthos* L.). Various beating techniques have also been used to sample insect populations on deciduous trees (White 1975, Bostanian & Herne 1980, Boivin & Stewart 1983, Burts & Brunner 1981).

The beating tray used in this experiment was a white circular tray (diameter 25 cm). The tray was filled with 70% ethyl alcohol to prevent the insects from escaping when they landed in the tray. A strong wooden stick was used to beat the branches of the tree (Plate 4(a)).

2.3.1.3 Sweep net

The advantages of a sweep net include its simplicity and speed, i.e. a high return for a small cost (Southwood 1978). No other method can capture as many insects from vegetation per human hour without both costing more for the equipment, and doing more damage to the crop (Ruesink & Kogan 1975). Also, it collects comparatively sparsely-dispersed species

(Southwood 1978).

The sweep net has often been criticised, yet it remains as one of the most popular methods for sampling insects in many crops. Sweeping is the most common method used in cotton for *Lygus* spp. bugs, even though it is the least precise because the sweep net is often unable to penetrate the plant canopy (Schotzko & O'Keefe 1986). Sweep net sampling is also the most widely used method in soybeans because no other method can capture as many insects from vegetation per hour of labour, without increasing cost and damage to the crop (Schotzko & O'Keefe 1986). Sweeping has also provided reliable estimates for *Lygus hesperus* Knight adults and nymphs in lentil fields (Schotzko & O'Keefe 1986), and it has been used extensively in the USA in several State pest management programmes against potato leafhopper in alfalfa (Fleischer *et al.* 1982).

Disadvantages of the sweep net include the fact that only those individuals on the top of the vegetation, that do not fall off or fly away on the approach of the collector, are caught (Southwood 1978). It is also somewhat subjective, with considerable variation in the efficiency of different collectors; usually the more rapidly the net is moved through the vegetation the larger the catch (Southwood 1978). Catches from the sweep net can also be effected by the habitat, the type of species being collected, the weather and the time of day when samples are collected (Ruesink & Kogan 1975)

An attempt was made here to standardise the sweep net sampling. Some of the disadvantages were overcome naturally, the only species of interest was the wattle mirid, and therefore differences in the efficiency of the sweep net in catching different species was not a factor.

Also only a single plant species (the black wattle) was sampled, and all the trees were of the same age. Other disadvantages were overcome by having the same person collecting the samples, by collecting at the same the time of the day, and in similar weather conditions.

The sweep net used in this experiment was a standard one with a diameter of 32 cm, and a handle length of 1 m. The net used was 50 cm long and had a mesh size of 1 mm (Plate 4(b)).

Plate 3: Instantaneous sampling method: D-vac machine

Plate 4: Instantaneous sampling methods: (a) beating tray, (b) sweep net

2.3.2 Cumulative trapping methods

In contrast to the active instantaneous sampling methods, there are also a wide range of passive techniques, in the form of sticky traps, pitfall traps and water pans. These methods come from the second category of relative population estimates (i.e. trapping). With these methods, the operator sets up the trap for a specified period of time and returns to remove the catch at a later date.

Sticky traps are of several basic designs, but most have been either large screens, or small cylinders, boxes or plates (Heathcote 1957). Sticky bands around branches or stems are also occasionally used. Sticky traps are mainly effective for the flying adults, unlike the instantaneous sampling methods which catch both adults and nymphs.

A number of studies have investigated the use of sticky traps, including monitoring of phytophagous mirids in an apple orchards (Boivin *et al.* 1982; Prokopy *et al.* 1979). These studies showed that the sticky traps detected the presence of the overwintered adults early in the season when they were difficult to capture by any other methods. Numerous studies in citrus orchards have also investigated the use of sticky traps (Samways *et al.* 1986; Samways *et al.* 1987; Samways 1986; Samways 1987; Van den Berg *et al.* 1991). These studies showed that florescent yellow sticky traps were extremely effective in detecting the presence of various citrus pests. Sticky traps have also been used effectively for the detection of pests on a variety of other crops; for example on sweet cherry (Van Steenwyk *et al.* 1990), lettuce (Yudin *et al.* 1987), palms (Cherry & Howard 1984), maple (Coli *et al.* 1992), cotton (Gerling & Horowitz 1984) and tomato (Gillespie & Quiring 1987).

The cumulative trapping methods used in this experiment were three different designs of sticky traps; a) the commercially available 'citrus' trap (14 cm x 7.5 cm) (Plate 5); b) a type of sticky board, constructed from 'masonite' (30 cm x 30 cm) and covered with a 'Fasson' yellow sticker (Plate 6); and c) a cylindrical trap constructed from plastic 2l 'Coke' bottles and covered with a 'Fasson' yellow sticker (38 cm x 14 cm) (Plate 7). All the traps were covered with a layer of clingfilm ('Gladwrap') and coated with a sticky substance, 'Flytac'.

Plate 5: Cumulative trapping method: Citrus trap

Plate 6: Cumulative trapping method: Sticky board

Plate 7: Cumulative trapping method: 'Coke' bottle trap

These traps were attached to a 2.4 m upright wooden pole and planted between the rows of trees up to a final height of 1.8 m.

These trapping methods were used at all of the sites and each method was replicated six times at each of the sites. The traps were left out in the plantation and collected after 14 days. On recovery, the traps were covered with another layer of clingfilm, sealing the flying insects between the two layers. The sample was then removed, and in the laboratory the adult wattle mirids were counted.

2.4 STATISTICAL METHODS

2.4.1 Transformation of data

The valid application of tests of significance requires that the experimental errors be independently and normally distributed with a common variance (Steel & Torrie 1981). The data did not follow a normal distribution, and therefore it was necessary to perform a transformation.

Taylor's (1961) Power Law was used to test the type of transformation required. The means and variances were calculated from the raw data collected with the sweep net samples and plotted on a log/log scale. Through Taylor's Power Law ($s^2 = ax^b$), b = 0.625, giving p a value of 0.69, this indicated that a square root transformation of raw data was appropriate (Elliott 1977). However, when very small values are involved, as in this case, where there were a number of zeros, the square root transformation tends to overcorrect (Steel & Torrie 1981). For this reason, Steel and Torrie (1981) recommend adding 0.5 to the square root. This was the final transformation used on the data here.

The data gathered from the cumulative trapping methods were also transformed to number of wattle mirids caught per trap per day. This compensated for any differences in the amount of time that the traps were left in the field.

2.4.2 Analysis of variance (ANOVA)

A one-way ANOVA is used to determine whether the means of a set of samples differ significantly (Alder & Roessler 1977). The total variation in a set of data is partitioned into components associated with possible sources of variability (Alder & Roessler 1977). Then the relative importance of the different sources is assessed by F-tests between each component of variation and the "error" variation (Steel & Torrie 1981). ANOVA assumes that the samples are independently drawn from normally distributed populations (Elliott 1977), this was not the case in the data from this experiment, therefore the ANOVA was calculated using the transformed data.

The computer programme Genstat was used to calculate the analysis of variance (ANOVA). The F values obtained from the ANOVA illustrated whether there were significant differences between the variables being tested. However, these results did not indicate where these differences lay, or which ones could be considered to be statistically significant (Steel & Torrie 1981). In order to test where these differences lay, further analysis, using the Least significant difference test, was done.

2.4.3 Least significant difference (LSD)

The least significant difference is defined as "the smallest difference which could exist between two significantly different sample means" (Alder & Roessler 1977). The F-ratio resulting from the ANOVA indicated significant differences between sample means. To test where these differences lay, the sample means were calculated, and from this the LSD was calculated for each of the ANOVAs done. The LSD was the most robust test for these type of data.

2.4.4 Correlation analysis

Correlation is a measure of the degree to which variables vary together (Steel & Torrie 1981). The closer the correlation coefficient lies to one, the better the correlation (Alder & Roessler 1977). Where linear correlation is poor the correlation coefficient lies close to zero (Alder & Roessler 1977).

Differences in trap area made it necessary to do other comparisons in order to test whether differences in the numbers of wattle mirids caught were 'real' or just a function of differences in trap area. The computer programme Statgraphics was used to do a correlation analysis.

2.5 RESULTS

2.5.1 Statistical background

2.5.1.1 Abbreviations used

The instantaneous sampling methods are abbreviated in the tables as follows: the sweep net (SW or SWEEP), the beating tray (BT or BEAT) and the D-vac machine (DV or D-VAC).

The cumulative trapping methods are abbreviated in the tables as follows: the 'masonite' sticky board (ST or STICKY), the commercially available citrus trap (CI or CITRUS) and the spherical 'Coke' bottle trap (CO or COKE).

The results from the LSD tests are summarised in the tables, in the column labelled "order", with the sampling method which performed the best being placed at the beginning of the list. The probability levels are given below the table, and the significance levels are indicated next to the results. One asterisk shows significance at the 5% level, and two asterisks shows significance at the 1% level. The abbreviation 'ns', indicates that there are no statistically significant differences.

Abbreviations in the ANOVA tables include: Degrees of Freedom (D.F.), Sums of Squares (S.S), Mean Square (M.S.), F-ratio (F.R.), Probability values (Prob.) Significance level (Sig.). One asterisk in the 'Sig.' column indicates significance at the 5% level, two asterisks indicates significance at the 1% level, three asterisks indicates significance greater than the 0.1% level. The abbreviation 'ns' indicates that there are no significant differences.

2.5.1.2 Results from ANOVA and LSD tests for adult wattle mirids - using instantaneous sampling methods

ANOVA was calculated for the adults (Table 1). The data were pooled and the means and standard errors (S.E.) (Fig. 2) were used to calculate the LSD test (Table 2).

Table 1. ANOVA of total number of adult wattle mirids caught - using instantaneous sampling methods.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F.R.	Prob.	Sig.
SITES	3	66.6	22.2	29.5	$P<0.001$	***
METHODS	2	224	112	149	$P<0.001$	***
DATES	4	175	43.7	57.9	$P<0.001$	***
SITES x METHODS	6	30.1	5.02	6.66	$P<0.001$	***
SITES x DATES	12	55.6	4.63	6.15	$P<0.001$	***
METHODS x DATES	8	52.2	6.53	8.66	$P<0.001$	***
SITES x METHODS x DATES	24	18.6	0.775	1.03	$P=0.428$	ns
ERROR	300	226	0.753			
TOTAL	359	848				

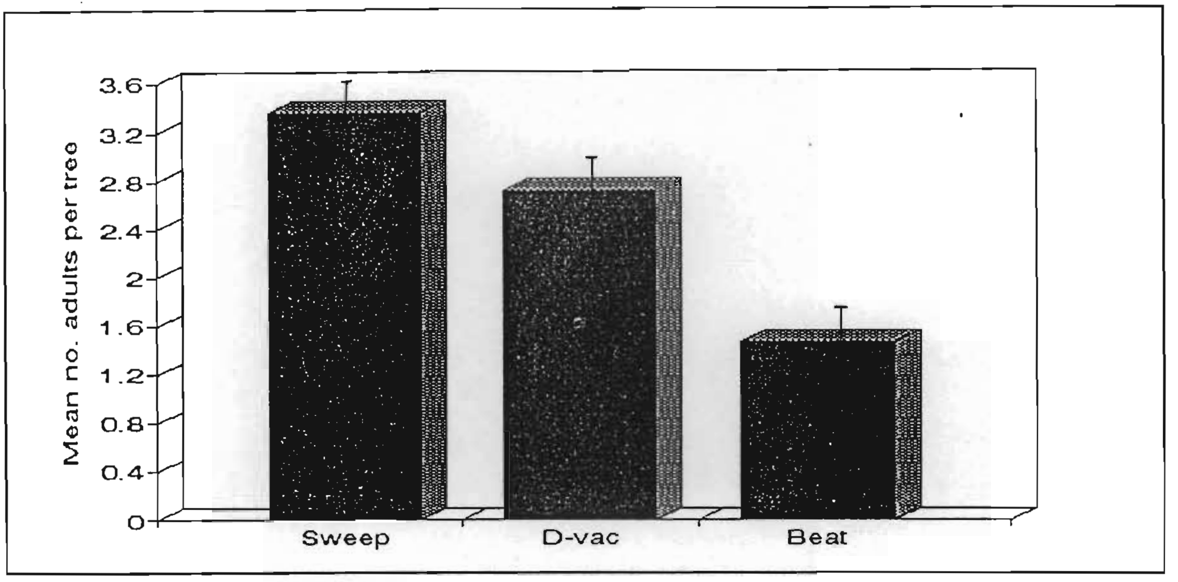

Figure 2. Mean (±1 S.E.) number of adult wattle mirids caught per tree using instantaneous sampling methods. Results pooled over all sites and all dates.

Table 2. Least significant differences between adult wattle mirids - using instantaneous sampling methods.

D-VAC VS BEAT	SWEEP VS BEAT	SWEEP VS D-VAC	ORDER
1.26**	1.90**	0.645**	SW DV BT

5% probability level = 0.220

1% probability level = 0.289

2.5.1.3 Results from ANOVA and LSD tests for wattle mirid nymphs - using instantaneous sampling methods

ANOVA was calculated for the nymphal instars (Table 3), and the means and standard errors (S.E.) (Fig. 3) were used to calculate the LSD test (Table 4).

Table 3. ANOVA of total number of wattle mirid nymphs caught - using instantaneous sampling methods.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F.R.	Prob.	Sig.
SITES	3	6.53	2.18	8.31	$P<0.001$	***
METHODS	2	79.9	39.9	152	$P<0.001$	***
DATES	4	14.8	3.69	14.1	$P<0.001$	***
SITES x METHODS	6	11.8	1.97	7.51	$P<0.001$	***
SITES x DATES	12	8.25	0.688	2.63	$P=0.002$	**
METHODS x DATES	8	6.68	0.835	3.19	$P=0.002$	**
SITES x METHODS x DATES	24	10.6	0.443	1.69	$P=0.025$	*
ERROR	300	78.6	0.262			
TOTAL	359	217				

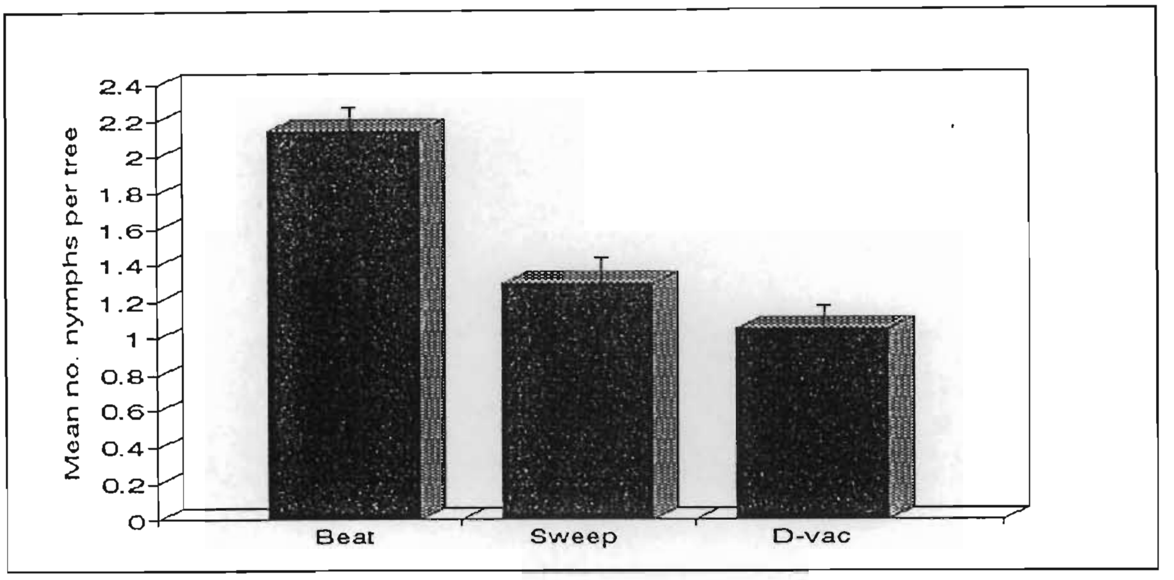

Figure 3. Mean (±1 S.E.) number of wattle mirid nymphs caught per tree using instantaneous sampling methods. Results pooled over all sites and all dates.

Table 4. Least significant differences between wattle mirid nymphs - using instantaneous sampling methods.

BEAT VS D-VAC	BEAT VS SWEEP	SWEEP VS D-VAC	ORDER
1.10**	0.852**	0.248**	BT SW DV

5% probability level = 0.130

1% probability level = 0.171

2.5.1.4 Results from ANOVA and LSD tests for adult wattle mirids - using cumulative trapping methods

The ANOVA was calculated (Table 5), and using the means and standard errors (S.E.) (Fig. 4), the LSD test was calculated for the adults (Table 6).

Table 5. ANOVA of total number of adult wattle mirids caught - using cumulative trapping methods.

SOURCE OF VARIATION	D.F	S.S	M.S	F.R.	Prob.	Sig.
SITES	3	1.30	0.432	54.7	$P < 0.001$	***
TRAPS	2	2.01	1.01	127	$P < 0.001$	***
DATES	7	12.6	1.80	228	$P < 0.001$	***
SITES x TRAPS	6	0.277	0.046	5.85	$P < 0.001$	***
SITES x DATES	21	2.03	0.097	12.3	$P < 0.001$	***
TRAPS x DATES	14	2.18	0.156	19.7	$P < 0.001$	***
SITES x TRAPS x DATES	42	0.926	0.022	2.79	$P < 0.001$	***
ERROR	480	3.79	0.008			
TOTAL	575	25.1				

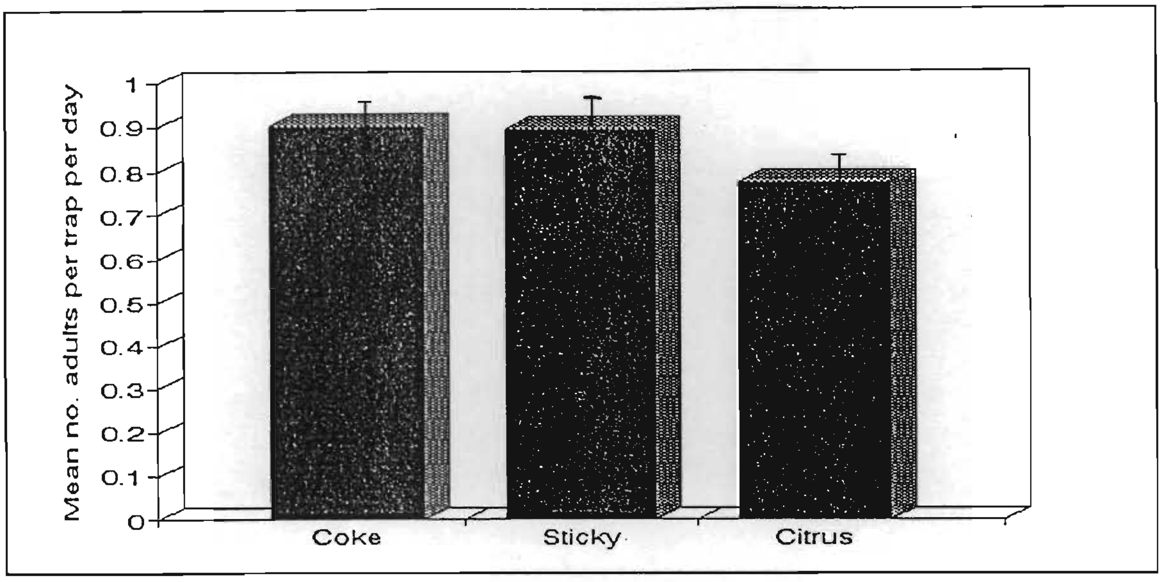

Figure 4. Mean (± 1 S.E.) number of adult wattle mirids caught per trap per day using cumulative trapping methods. Results pooled over all sites and all dates.

Table 6. Least significant differences between adult wattle mirids - using cumulative trapping methods.

STICKY VS CITRUS	COKE VS CITRUS	COKE VS STICKY	ORDER
0.122**	0.129**	0.007 ns	CO ST CI

5% probability level = 0.018

1% probability level = 0.023

2.5.2 Instantaneous sampling methods

The results from the instantaneous sampling methods showed that the sweep net captured the most adults (Table 2). However, the beating tray was the most effective method for the capture of the nymphal stages (Table 4).

2.5.3 Cumulative trapping methods

The results from the cumulative trapping techniques showed that the 'Coke' bottle trap caught more adult wattle mirids than the sticky board trap, but that these differences were not significant. Both traps however, performed highly significantly differently, at the 1% level, from the citrus trap (Table 6).

2.5.4 The effect of infestation

The four sites all had different infestation levels at the start of the experiment. The differences between these sites were highly significant, as indicated by the results from the ANOVA (Tables 1, 3 & 5). To investigate whether certain trapping techniques had better performances at certain sites, the means and standard errors (S.E.) at each of the sites were calculated (Figs 5 - 7) and LSD tests were done (Tables 7 - 14).

2.5.4.1 Results from LSD tests for instantaneous sampling methods

2.5.4.1.1 Adults

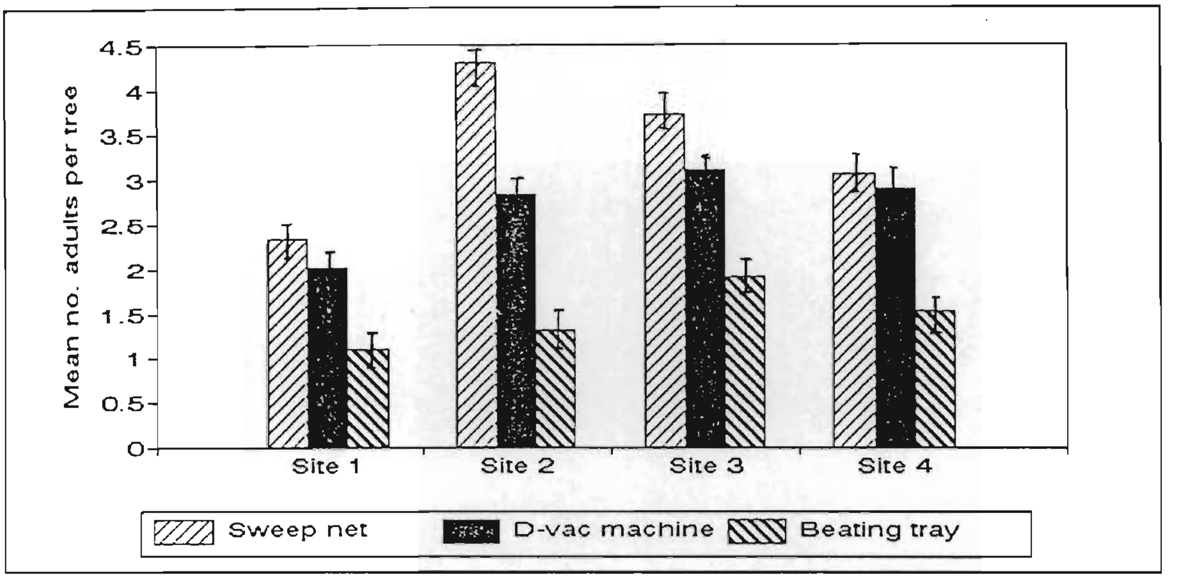

Figure 5. Mean (±1 S.E.) number of adult wattle mirids caught per tree using instantaneous sampling methdods at each of the sites. Results pooled over all dates for each of the four sites

Table 7. LSD test at site 1 based on adult wattle mirids caught using instantaneous sampling methods.

SW VS DV	DV VS BT	SW VS BT	ORDER
0.392 ns	0.908**	1.24**	SW DV BT

5% probability level = 0.439

1% probability level = 0.578

Table 8. LSD test at site 2 based on adult wattle mirids caught using instantaneous sampling methods.

SW VS DV	DV VS BT	SW VS BT	ORDER
1.47**	1.53**	3.00**	SW DV BT

5% probability level = 0.439

1% probability level = 0.578

Table 9. LSD test at site 3 based on adult wattle mirids caught using instantaneous sampling methods.

SW VS DV	DV VS BT	SW VS BT	ORDER
0.614**	1.21**	1.83**	SW DV BT

5% probability level = 0.439

1% probability level = 0.578

Table 10. LSD test at site 4 based on adult wattle mirids caught using instantaneous sampling methods.

SW VS DV	DV VS BT	SW VS BT	ORDER
0.165 ns	1.37**	1.54**	SW DV BT

5% probability level = 0.439

1% probability level = 0.578

Results from instantaneous sampling methods, for adult wattle mirids caught (Tables 7 -10), showed that at Sites 2 and 3, the sweep net had a highly significantly better catch than either the D-Vac machine or the beating tray (Tables 8 & 9). At Sites 1 and 4 there were no significant differences between the sweep net and the D-vac machine, however in each case the sweep net caught more individuals than the D-vac machine (Tables 7 & 10). At all the sites, the beating tray caught the least number of adult wattle mirids.

2.5.4.1.2 Nymphs

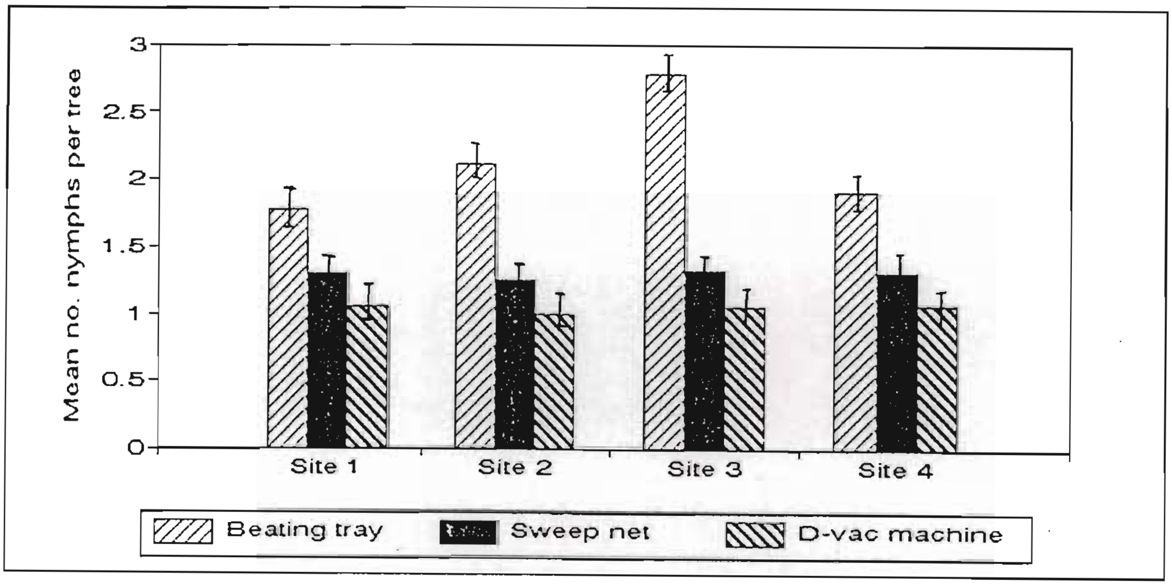

Figure 6. Mean (±1 S.E.) number of wattle mirid nymphs caught per tree using instantaneous sampling methods at each of the sites. Results pooled over all dates for each of the four sites.

Table 11. LSD test at site 1 based on wattle mirid nymphs caught using instantaneous sampling methods.

BT VS SW	BT VS DV	SW VS DV	ORDER
0.485**	0.720**	0.235 ns	BT SW DV

5% probability level = 0.259

1% probability level = 0.341

Table 12. LSD test at site 2 based on wattle mirid nymphs caught using instantaneous sampling methods.

BT VS SW	BT VS DV	SW VS DV	ORDER
0.856**	1.11**	0.251 ns	BT SW DV

5% probability level = 0.259

1% probability level = 0.341

Table 13. LSD test at site 3 based on wattle mirid nymphs caught using instantaneous sampling methods.

BT VS SW	BT VS DV	SW VS DV	ORDER
1.46**	1.73**	0.267*	BT SW DV

5% probability level = 0.259

1% probability level = 0.341

Table 14. LSD test at site 4 based on wattle mirid nymphs caught using instantaneous sampling methods.

BT VS SW	BT VS DV	SW VS DV	ORDER
0.603**	0.841**	0.238 ns	BT SW DV

5% probability level = 0.259

1% probability level = 0.341

Results from instantaneous sampling methods for the capture of nymphs (Tables 11 - 14), showed that at all sites the beating tray had a significantly higher catch of nymphs than either the sweep net or the D-vac machine.

At Sites 1, 3 and 4 there were no significant differences between the sweep net and the D-vac machine, however in each case the sweep net had a slightly higher catch of nymphs. At Site 3 the sweep net had a significantly higher catch than the D-vac machine (Table 13).

2.5.4.2 Results from LSD tests for cumulative trapping methods

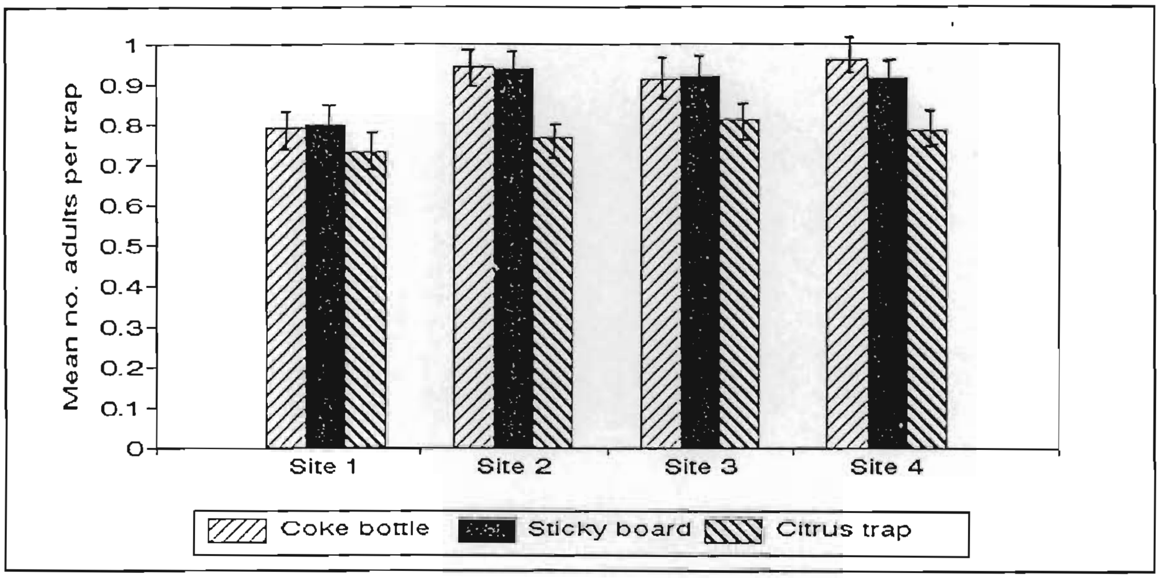

Figure 7. Mean (± 1 S.E.) number of adult wattle mirids caught per trap per day using cumulative methods at each of the sites. Results pooled over all dates for each of the four sites.

Table 15. LSD test at site 1 based on adult wattle mirids caught using cumulative trapping methods.

ST VS CI	CO VS CI	CO VS ST	ORDER
0.071**	0.064**	-0.007 ns	ST CO CI

5% probability level = 0.036

1% probability level = 0.047

Table 16. LSD test at site 2 based on adult wattle mirids caught using cumulative trapping methods.

ST VS CI	CO VS CI	CO VS ST	ORDER
0.174**	0.178**	0.004 ns	CO ST CI

5% probability level = 0.036

1% probability level = 0.047

Table 17. LSD test at site 3 based on adult wattle mirids caught using cumulative trapping methods.

ST VS CI	CO VS CI	CO VS ST	ORDER
0.108**	0.097**	-0.011 ns	ST CO CI

5% probability level = 0.036

1% probability level = 0.047

Table 18. LSD test at site 4 based on adult wattle mirids caught using cumulative trapping methods.

ST VS CI	CO VS CI	CO VS ST	ORDER
0.133**	0.177**	0.043*	CO ST CI

5% probability level = 0.036

1% probability level = 0.047

Results from cumulative trapping methods (Tables 15 - 18) showed that irrespective of site, the citrus trap had the lowest catch.

At Sites 1 and 3, there were no significant differences between the sticky board and the 'Coke' bottle, but the sticky board caught more individuals (Tables 15 & 17). At Sites 2 and 4, where the infestation was medium, the 'Coke' bottle trap caught more adult wattle mirids than the sticky board (Tables 16 & 18). At Site 4 these differences were statistically significant at the 5% level (Table 18).

2.5.5 Correlation of sweep net and sticky traps

Results from the ANOVA and LSD tests supported the use of the sweep net for the capture of adult stages of the wattle mirid. It was possible to compare the cumulative traps with the catches from the sweep net. To do this, a correlation analysis, using the computer program Statgraphics, tested which traps were most highly correlated with the catches from the sweep net (Table 19).

Table 19. Correlation coefficients and significance levels, comparing sweep net and sticky traps, for total number of adult wattle mirids caught.

	CITRUS TRAP	COKE BOTTLE	STICKY BOARD
SWEEP NET	0.527	0.756	0.758
SIG. LEVEL	***	***	***
PROB. LEVEL	$P < 0.001$	$P < 0.001$	$P < 0.001$

Results showed that all the correlations were highly significant. However, the sticky board, with a correlation coefficient of 0.758, was the cumulative trap which closely approximated the catches made with the sweep net. This was followed by the 'Coke' bottle trap, with a correlation coefficient of 0.756, and finally by the citrus trap with a correlation coefficient of 0.527. These results supported those from the ANOVA and the LSD tests.

2.5.6 Cost analysis

The various types of sticky traps are all equally easy to use. Statistical differences between the 'Coke' bottle traps and the sticky traps were slight. The additional factor of cost was taken into account to make a commercially viable recommendation for the most practical trapping method.

All traps made use of clingfilm ('Gladwrap'), poles for attachment and the sticky substance ('Flytac'). Therefore these factors were not considered, as the cost for all traps was equal. The only factors taken into account were the prices of the traps themselves (Table 20).

Table 20. Prices of traps (June 1994).

TRAP TYPE	COST
CITRUS TRAP	R 0.35
COKE BOTTLE	R 2.60
STICKY BOARD	R 3.10

These results showed that the citrus trap was by far the cheapest. However, it was the least efficient and therefore was not considered for the monitoring of the wattle mirid. The 'Coke' bottle trap was cheaper than the sticky board. The most expensive aspect of the sticky board trap was the 'masonite' board, masonite is relatively cheap in comparison to other materials (e.g. glass or plastic plates), therefore this cost cannot be reduced by making use of alternative materials. The most expensive factor in the production of the 'Coke' bottle trap was the 'Fasson' yellow sticker. Other experiments tested alternatives to the 'Fasson' stickers which were cheaper (See chapter 3).

Results from these analyses suggested that since there was no statistical separation between the 'Coke' bottle trap and the sticky board, the cheaper price of the 'Coke' bottle made it the most practical method.

2.6 DISCUSSION

2.6.1 Instantaneous sampling methods

2.6.1.1 Adults

The sweep net had a significantly higher catch of adults, than either the D-vac machine or the beating tray.

A study on *Lygus hesperus* adults and nymphs in lentil fields (Schotzko and O'Keefe 1986), also found that the sweep net provided more reliable estimates when compared with D-vac sampling methods.

At Sites 2 and 3, where the infestation levels were medium and high respectively, the sweep net had a significantly better performance than the D-Vac machine. At Sites 1 and 4, where the infestation level was lower, there were no significant differences between the performance of the sweep net and the D-Vac machine.

The sweep net is considered to be a useful method for capturing adult insects in flight and when they drop off the leaves (Southwood 1978). In areas of low infestation, there were less adult wattle mirids moving between the trees, making it difficult for capture with a sweep net. The D-Vac machine improved in performance because it actively removed the insects from the branches of the tree by means of suction.

At Sites 1 and 4, the sweep net samples caught a high proportion of the adult population early in the season, but showed a decrease in sensitivity later, at a time when the D-vac machine was showing a slight increase. Similar trends were observed at Sites 2 and 3, although they were not as marked as those at Sites 1 and 4. These results were similar to those obtained by Fleischer *et al.* (1985) in their study of *Lygus lineolaris* on cotton. They suggested that this may be due to decreasing efficiency of the sweep net as the plants increased in size (Fleischer *et al.* 1985).

2.6.1.2 Nymphs

The results supported the use of the beating tray for the capture of the nymphal stages of the wattle mirid. The beating tray was also the best method of capture for nymphs irrespective of site, or infestation level. The nymphs are readily dislodged from the tree when the branches are struck with the wooden stick.

The superior performance of the beating tray in comparison to the D-vac machine was found to be similar to those results obtained by Herms *et al.* (1990), in their study of five species of phytophagous Hemiptera on mature honeylocust. Results from their study indicated that the beating trays captured proportionally more early instars (Herms *et al.* 1990). They suggested that the relative inability of the D-vac machine to sample early instars may be caused by suction insufficient to dislodge insects with a small body size from within the expanding (but still curled) leaflets in which they feed (Herms *et al.* 1990). This also applies to wattle mirid nymphs feeding in wattle trees. Similarly, the sweep net performed better than the D-vac machine, since the sweep net, like the beating tray, dislodges the nymphs when it is swept through the canopy of the tree.

There were no significant differences between the sweep net and the D-vac machine at Sites 1, 2, and 4. However, in all cases, the sweep net had a slightly higher catch than the D-vac machine. At site 3 the sweep net had a significantly higher catch than the D-vac machine. Site 3 had a high infestation level and it possible that this accounts for the difference.

2.6.1.3 Reasons for discarding the D-vac machine

Initial analysis done during the experiment showed that the D-vac was not efficient for the capture of the wattle mirid, and it was discarded from the monitoring methods in June 1994.

The D-vac machine is a useful tool, but in practice it is expensive (approximately R10 000) which puts it beyond the range of the majority of woodlot and commercial foresters. In spite of its usefulness, there are several other problems with the D-vac (Summers *et al.* 1984). Its efficiency is affected by the mode of operation; the nozzle must be moved vertically into the foliage and down to the ground (Southwood 1978), this requires some practice before the user becomes proficient. The efficiency of suction samplers is also affected by other factors, of particular importance are the nozzle wind speed (for heavy and/or tenacious species) and speed of enclosure (for active flying species) (Southwood 1978). The D-vac is excellent for the capture of flying species, but the nozzle wind speed does not allow for the collection of the heavier species (Southwood 1978). Other common problems are the weight and cumbersome distribution of the external piping (Dolling 1991), and the amount of labour required to obtain accurate samples. Also it has an excessively high noise level, and the mounting of the throttle control necessitates running the machine at essentially full throttle, even between sampling periods, to maintain a relatively constant suction (which adds to fuel costs). Furthermore, there are often breakdowns and subsequent difficulties in getting the machine repaired (Summers *et al.* 1984). It is also ineffective for sampling of Hemiptera from tall or wet vegetation (Dolling 1991).

These problems were highlighted during these experiments. Perhaps the most obvious problem encountered was the rapid dispersion of the wattle mirids on the approach of the machine. The approach of a person without the machine also caused the wattle mirids to take flight. However, the excessive noise and vibration of the D-vac machine exaggerated this, making it an ineffective method for accurate representation of the wattle mirid population.

2.6.2 Cumulative trapping methods

Results indicated that the citrus trap was a poor method of monitoring the population level of the wattle mirid, and it was therefore eliminated from the selection process. These results corroborated those gained from a preliminary study (Atkinson & Stewart 1993).

The performances of the sticky board and the 'Coke' bottle trap were variable within sites and appeared to depend on the infestation level of the wattle mirid population. The 'Coke' bottle trap caught slightly more wattle mirids than the sticky board, but these differences were not statistically significant.

At sites 2 and 4 where the infestation levels were medium the 'Coke' bottle caught a higher number of wattle mirids than the sticky board trap, at Site 4 this difference was statistically significant at the 5% level. Reasons for this significance are possibly due to a difference in the altitudes and rainfall patterns of the two sites. All the other sites were at the Greenpoint plantation, while Site 4 was at the Bloemendal Experiment Station. At the remaining two sites, the sticky board caught slightly more wattle mirids than the 'Coke' bottle trap but there were no statistically significant differences between the two.

2.6.3 Correlation of sweep net and sticky traps

Results from the correlation analysis suggested that the sticky board and the 'Coke' bottle results were the ones which were most closely correlated with the catches made with the sweep net. Differences between these two traps were very slight. The correlation with regards to the citrus trap was far weaker.

The strong correlations were in contrast to the results obtained by Atkinson and Stewart (1993) who found that trap catches did not correlate with catches made with the sweep net. Reasons for these differences are possibly due to differences in the sites, ages of trees in the plantations, and the more intensive investigation carried out here.

2.6.4 Advantages of sticky traps

Sticky traps have a number of benefits for use in the wattle industry. Samways *et al.* (1986), summarise the advantages and disadvantages of sticky traps:

1) Traps provide an early warning system and can be used for predictive purposes.

2) They are convenient and easy to operate, being prepared and scanned in relative comfort of the laboratory.

3) The traps determine when and where control measures are required, and therefore promote

minimum and effective use of insecticides.

4) The traps are continually in operation and avoid the subjectivity that can be associated with visual counting.

5) Save time.

6) Double checking of the traps is always possible because the insects are still present and the results can be stored permanently simply by using a double layer of clingfilm.

7) The traps need not be used alone, but they can be confirmed first hand by the use of other methods once the trap has provided a warning.

2.6.5 Disadvantage of sticky traps

1) It may take a little time to get used to identifying the insect.

These reasons make the sticky trap a very attractive option for use in forestry, particularly for the monitoring of the wattle mirid. The disadvantage, stated by Samways *et al* (1986) is easily overcome, because the wattle mirid is relatively large and easy to distinguish from other insects.

2.7 CONCLUSIONS

2.7.1 Suggestions for the most practical instantaneous sampling method

Both adults and nymphs cause economic damage to wattle trees (Fletcher 1994). Therefore, it is important to select a method which can capture both stages, instantaneous trapping methods are active methods and capture both nymphal and adult life-stages of the wattle mirid. However, the beating tray is not a practical means of capturing the adult as it easily flies away from the tray.

Statistically, the results favoured the use of the sweep net for the capture of adult wattle mirids. The sweep net is practical and is a standard sampling method used in entomological studies. The sweep net was also more effective, less laborious and less costly than the D-vac machine. In short, the sweep net was the preferred instantaneous sampling method for the capture of the adult stages of the wattle mirid.

The beating tray was the most practical method for capture of the nymphal stages. The nymphs were less mobile than the adults and the beating tray relied on this.

2.7.2 Suggestions for the most practical cumulative trapping method

The cumulative traps are favoured for use in forestry, as they collect the wattle mirids continuously and provide a relatively large return for the amount of time spent working with them. They are less labour intensive than the instantaneous methods, and are therefore cheaper.

Among the cumulative trapping methods the citrus trap was discarded as being the least effective.

There were no statistical differences separating the 'Coke' bottle trap and the sticky board. Correlation analysis of the sweep net and the cumulative trapping methods supported the use of the sticky board. However, cost analysis supported the use of the 'Coke' bottle.

In the interests of producing a cheap, practical and reliable trapping technique, the 'Coke' bottle trap was chosen for future experiments (see subsequent chapters).

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CHAPTER 3

CHOICE OF TRAP COLOUR AND HUE

SUMMARY

The aim here was to ascertain whether *Lygidolon laevigatum* showed a stronger positive taxis to one colour of sticky trap. The traps were cylindrical plastic traps, constructed from 2 litre plastic 'Coke' bottles. Five colours and one control were chosen. The control was an uncovered, transparent 'Coke' bottle. The five colours were the ones available from the 'Fasson' range of stickers, and included, green, blue, black, white and yellow. Results showed that yellow was the most attractive colour. *L. laevigatum* was then tested for its taxis to six different hues of yellow. Four of the hues were from the 'Dulux' range of paints, the fifth hue was a standard paint from the 'Decade' range, and the sixth hue was a 'Fasson' yellow sticker. There were no significant differences between the hues of yellow. As the paints were cheaper than the 'Fasson' sticker, it was recommended that the forester use a yellow paint, preferably 'Golden yellow' (Decade paint: Code SGE 08*B49), which was the cheapest.

3.1 INTRODUCTION

Sticky traps have been widely used for trapping small winged insects, mainly agricultural pests (Dent 1991). In the majority of cases, the trap depends mainly on vision, odour or chemical factors to attract the insects (Muirhead-Thomson 1991), and the sticky surface acts purely as a retentive or retaining element. Insects use these visual, chemical, and tactile cues in the location and recognition of their host plants (Atkins 1980).

Insects are capable of perceiving colour, and are particularly sensitive to the ultra-violet and blue-green part of the spectrum (Atkins 1980). The visual pigments of insects absorb different wavelengths of light unequally, consequently their light receptors are stimulated by some wavelengths and not by others (Atkins 1980). Although there is considerable variation in terms of the wavelengths detected by different species, insects as a group are sensitive to wavelengths from about 240 nm (ultraviolet) to 650 nm (yellow-orange), compared to the human eye which is sensitive to wavelengths from about 400 nm (blue-violet) to 800 nm (red) (Atkins 1980).

Moericke (1969) suggested that aphids were able to perceive colour in terms of hue, tint and intensity. Kring (1967) found that *Aphis nasturtii* Kaltenbach was more attracted to full yellow than to lighter tints of yellow. The explanation he gave was that the addition of white not only decreased the reflectance, but also altered the hue, so that more light was reflected in the blue portion of the spectrum (Kring 1967). Field studies on the attraction of *Ctenarytaina thysanura* (Ferris & Klyver), a psyllid, to coloured traps, also showed that this insect was sensitive to different tints of yellow, responding more strongly to pure yellow than to yellow tints diluted with white (Mensah & Madden 1992).

The literature indicates that yellow is the most important colour for attracting sap-sucking insects. Prokopy and Owens (1983) showed that many diurnal insects can be captured on non-UV-reflecting white, yellow and red traps, that are bud, or flower, bark or foliage mimics. They hypothesise that a positive response to yellow may characterise the majority of foliage seeking insects (Prokopy & Owens 1983). The attraction of yellow may be related to host colour as a supernormal stimulus (Prokopy & Owens 1983).

For herbivores that respond positively to the visual stimulus of foliage reflectance, green pigments, and more commonly yellow pigments (which act as a supernormal stimuli), have proven to be valuable in management programmes against various insect pests when incorporated into traps for monitoring (Berlinger 1980; Capinera & Walmsley 1978; Ferro & Suchak 1980; Meyerdirk & Oldfield 1985; Samways 1987; Coli *et al*. 1992).

Not all insects are attracted to yellow. The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), which is a mirid, does not respond any more strongly to yellow than to clear glass (Prokopy *et al*. 1979). Studies on colour perception of honey bees have shown that they respond more strongly to blue and violet, than to yellow-green or yellow, and are unable to distinguish red from black because both are perceived as non-colours (Atkins 1980). Experiments testing the attractiveness of different colours to the planthopper, *Myndus crudus* Van Duzee, have shown that this homopteran is attracted to blue (Cherry & Howard 1984). White is also commonly used for the monitoring of various insect pests (Beavers *et al*. 1971; Yudin *et al*. 1987; Stewart & Gaylor 1991).

The aims of these experiments were: 1) to determine whether *Lygidolon laevigatum* showed strong positive phototaxis to one particular colour, and once these results were obtained, 2) to then determine whether it was strongly attracted to one particular hue of that colour.

3.2 STUDY SITES

3.2.1 Experiment with colour

Initially one study site was chosen. This was at "Greenhill", a Mondi plantation, near Richmond (29°50'S 30°19'E; elevation 1038 m). Once an infestation was reported, the trees at the site were sampled with a sweep net and found to have a medium infestation, with about 5 adult wattle mirids per tree.

After two weeks, an additional site was included in the experiment. This site was in Hilton, at "Mountain Home", a Mondi plantation (29°33'S 30°35'E; elevation 1094m). This site had a medium to high infestation, with about 6 adult wattle mirids per tree.

As the experiment was intensive, it meant that the sites had to have reached a relatively high infestation level before they were suitable. As soon as an infestation had been reported at Richmond, the experiment was set up. The additional site in Hilton was chosen once a suitably high infestation was reported, and verified through sweep net sampling.

The experiment continued for one month, from 21 March to 11 April 1995. The site at Richmond was used during the initial two weeks, and during the final two weeks both the sites were used.

3.2.2 Experiment with hue

The same two sites at Hilton and Richmond were used throughout this experiment, which continued for one month, from 20th April to 9th May 1995.

3.3 MATERIALS AND METHODS

As explained in the first chapter (Pg. 66), the 'Coke' bottle traps were used in these experiments. The 'Coke' bottles were covered with a layer of clingfilm ('Gladwrap') and coated with a sticky substance 'Flytac'. The traps were attached to a 2 m pole and planted between the rows of trees to a final height of 1.5 m. The experiments were based on a randomised design, which was explained on pg. 28. Each of the colours or hues were replicated 5 times at each of the sites.

Each experiment continued for a total of four weeks. The traps were left out in the plantation for 1 week and then collected. On recovery, the traps were covered with another layer of clingfilm, sealing the insects between the two layers. The sample was then removed and taken back to the laboratory where the adult wattle mirids were counted.

Reflectance wavelengths for each of the colours and hues were calculated using a UV-vis scanning spectrophotometer with an integrating sphere attachment. The machine was run at a slit width of 5.0, and the scan speed was fast. This was done at the Chemistry Department, University of Natal, Pietermaritzburg.

3.3.1 Experiment with colour

'Fasson' stickers were used to cover the 'Coke' bottles with one of the five different colours. The colours used were: black, white, blue, green and yellow. These represented the range of 'Fasson' stickers which were chosen on the basis of their practical use. The control was an uncovered 'Coke' bottle, which was transparent.

Spectral reflectance curves given in Prokopy and Owens (1978) suggest that: green is a rough mimic, and yellow is a "supernormal" stimulus, of foliage reflectance. Black is a mimic of bark reflectance, and white is considered to be a "supernormal" mimic of apple buds and blossoms. Clear plastic was chosen as the control, as it is considered to be a neutral surface (Prokopy *et al.* 1979).

3.3.2 Experiment with hue

Once the results from the experiment with colour were obtained, an experiment testing the phototactic response of *L. laevigatum* to different hues of the most attractive colour were tested. Paints of varying hues of yellow were used. The 'Coke' bottles were painted, simply by placing a small amount of paint within the bottle when it was held upright, the paint was then swirled around the bottle until the entire inside surface was coated. Any excess paint was poured out and used in another bottle.

Five paints, as well as the 'Fasson' yellow sticker (stuck on the outside of the 'Coke' bottle) were used. Four of the paints were from the 'Dulux' range. The paints (and their codes) were: slicker (39YY66/813), citrus (45YY62/805), bright lights (60YY62/755), neon light (66YY56/707). The fifth paint was a standard yellow paint from the 'Decade' range, Golden yellow (SGE 08*B49).

3.4 STATISTICAL METHODS

3.4.1 Transformation of data

The data were not normally distributed, making it necessary to transform for parametric statistics. A transformation for wattle mirids had already been worked out using Taylor's (1961) power law (pg. 37). The square root plus 0.5 transformation was therefore also used on the data gathered from these experiments, for the same reasons as already explained (pg. 37).

3.4.2 Analysis of variance (ANOVA) used in experiment on colour

ANOVA has been explained in Chapter 2 (pg. 38) and was used on these data for the same reasons. The computer program Genstat was used to calculate the mean values and the ANOVA.

The literature highlighted the importance of the colour yellow in attracting sap sucking insects. Therefore, before the experiment began, it was decided to separate the degrees of freedom for colour and to create a matrix, in which yellow was separated and compared with the rest of the colours; and the other colours were compared among themselves. The resulting F values obtained in the ANOVA would then illustrate whether there were significant differences when comparing yellow to the other colours.

3.5 RESULTS

3.5.1 Abbreviations used

The colours used in the first experiment are abbreviated in the figures as follows: Blue (BLU), Green (GRE), White (WHI), Black (BLA), Yellow (YEL), and the transparent control (CON).

The yellow hues are abbreviated in the figures as follows: the 'Fasson' sticker (FAS), the 'Dulux' paints; 'Slicker' (SLI), 'Citrus' (CIT), 'Neon light' (NEO), and 'Bright lights' (BRI); and finally the 'Decade' paint, 'Golden yellow' (GOL).

Abbreviations used in the ANOVA tables are the same as those used in Chapter 2 (Pg. 40).

3.5.2 Experiment with colour

3.5.2.1 Spectral Reflectance

The spectral reflectance curves of the colours are illustrated in Figure 8, and the wavelengths are tabulated below (Table 21).

Table 21. Wavelengths of various colours and their percentage reflectance, excluding black and the transparent control.

COLOUR	WAVELENGTH (nm)	REFLECTANCE (%)
Yellow	565	89
Green	517.6	35.4
Blue	448.6	23.6
White	420	91

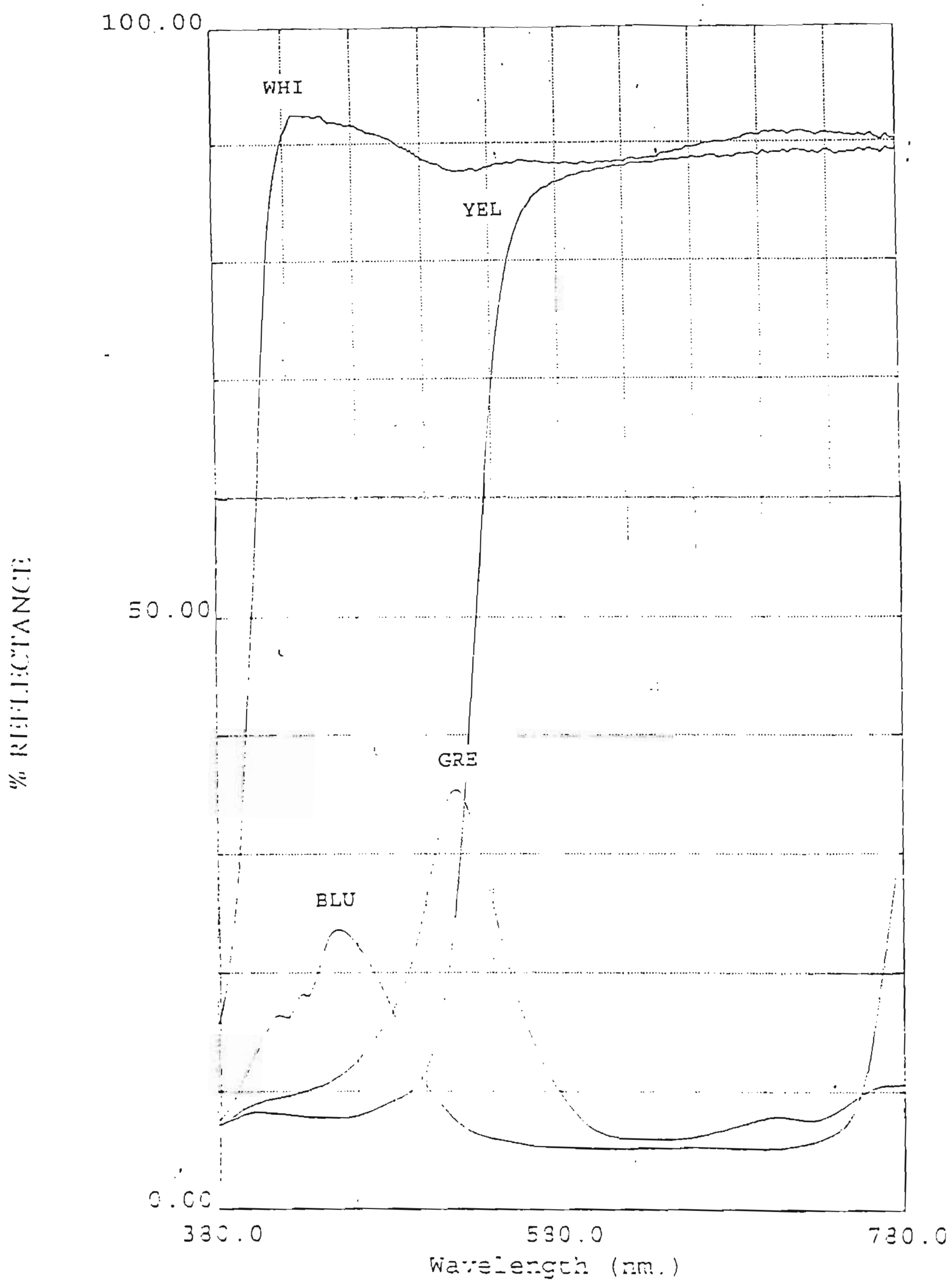

Figure 8. Spectral reflectance curves of the colours used to test the phototactic response of *L. laevigatum*. Black and the transparent control are not illustrated as they did not register on the spectrograph, and they did not have specific wavelengths.

3.5.2.2 ANOVA

An ANOVA was done (Table 22) to compare the two sites for the two dates when they were both sampled. The results illustrated that there were highly significant differences between the colours and the sites, but that the colour by site interaction was not significant, indicating that the charactersitics of the sites did not affect the insects response to colour. However, to determine which colours were contributing to the significance level at each of the sites, the data were analysed separately for each site, comapring yellow to the other colours.

Table 22. ANOVA comparing different colours for the capture of adult wattle mirids at the two sites over two weeks.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F.R.	Prob.	Sig.
SITE	1	9.29	9.29	23.6	$P < 0.001$	***
COLOUR	5	13.0	2.60	6.61	$P < 0.001$	***
SITE X COLOUR	5	2.56	0.512	1.30	$P = 0.268$	ns
ERROR	108	42.5	0.393			
TOTAL	119	67.3				

3.5.2.2.1 Richmond

The experiment was carried for a total of four weeks at Richmond. An ANOVA was carried out (Table 23). The degrees of freedom for colour were separated, so that yellow could be compared with the other colours.

Table 23. ANOVA comparing different colours for the capture of adult wattle mirids at Richmond, over four weeks.

SOURCE OF VARIATION	D.F.	S.S	M.S.	F.R.	Prob.	Sig.
COLOUR	5	6.26	1.25	1.73	$P=0.133$	ns
YELLOW VS OTHERS	1	3.86	3.86	5.34	$P=0.023$	*
OTHER COLOURS	4	2.39	0.598	0.83	$P=0.511$	ns
ERROR	114	82.4	0.723			
TOTAL	119	88.7				

When the colours were all compared together there were no significant differences between them. However, when yellow was compared to the other colours, it was significantly different from them.

The means and the standard errors (S.E.) for the number of adults caught, were calculated (Fig. 9) and comparisons were made between the colours. Yellow caught the highest mean number of wattle mirids, while the control caught the lowest. Black caught a higher number than green, followed by blue and finally by white.

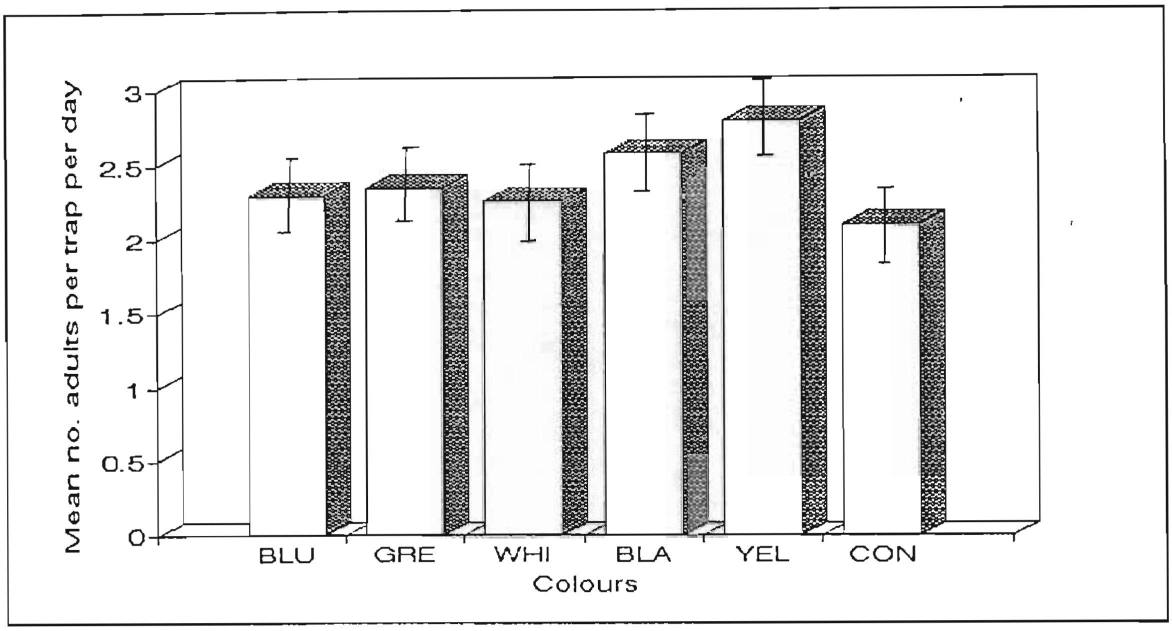

Figure 9. Mean (± 1 S.E.) number of adult wattle mirids caught per trap per day on different coloured traps at Richmond.

3.5.2.2.2 Hilton

The experiment was carried out for two weeks at Hilton. Analysis was done using ANOVA (Table 24). The colours were separated so that yellow could be compared to the other colours.

Table 24. ANOVA comparing different colours for the capture of adult wattle mirids at Hilton over two weeks.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F.R	Prob.	Sig.
COLOUR	5	4.88	0.976	2.83	$P=0.003$	**
YELLOW VS OTHERS	1	2.66	2.66	7.72	$P<0.001$	***
OTHER COLOURS	4	2.22	0.554	1.60	$P=0.284$	ns
ERROR	54	18.6	0.345			
TOTAL	59	23.5				

Results from the ANOVA showed that there were highly significant differences between the colours. When yellow was compared with the rest, the results showed that yellow was very highly significantly different from the other colours. But, when the other colours (excluding yellow) were compared to each other, the differences became non-significant. This illustrates that the significant difference between colours is due almost entirely to the colour yellow.

The means and standard errors (S.E.) of the numbers of individuals caught were calculated (Fig. 10) and comparisons were made between the colours.

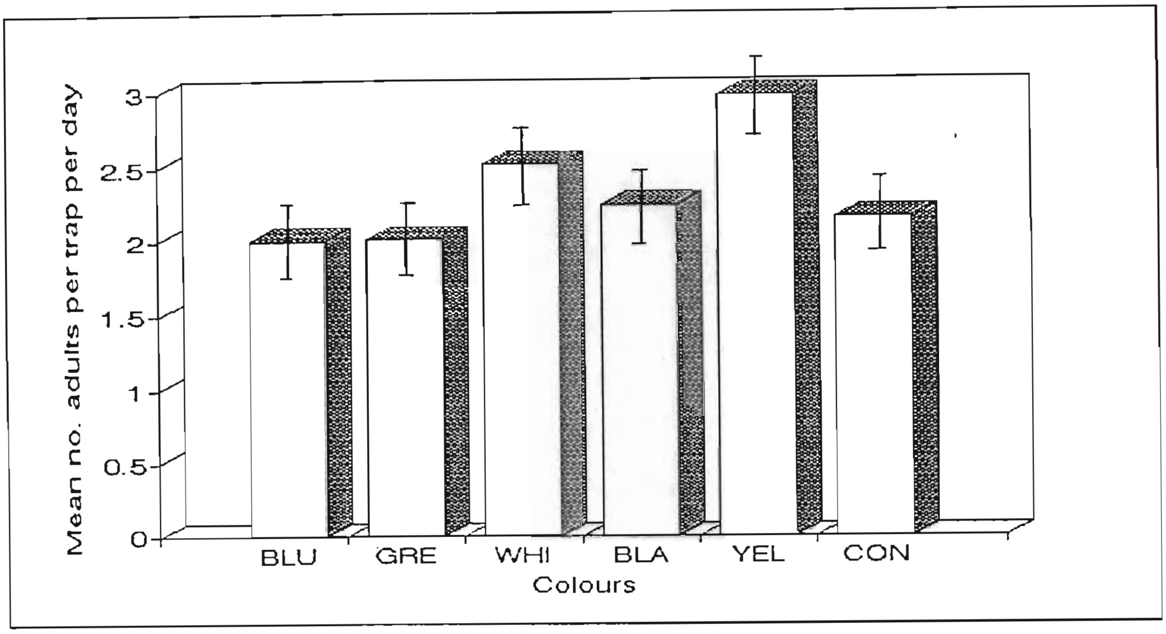

Figure 10. Mean (± 1 S.E.) number of adult wattle mirids caught per trap per day on different coloured traps at Hilton

These results showed that the yellow traps caught more wattle mirids than any of the other coloured traps. This was followed by white, black, the control, green and finally by blue.

3.5.3 Experiment with hue

3.5.3.1 Spectral reflectance

Results from the experiment on colour had indicated that yellow was the most attractive colour. The spectral reflectance curves of the different hues are illustrated in figure 11, and the wavelengths are tabulated below (Table 25).

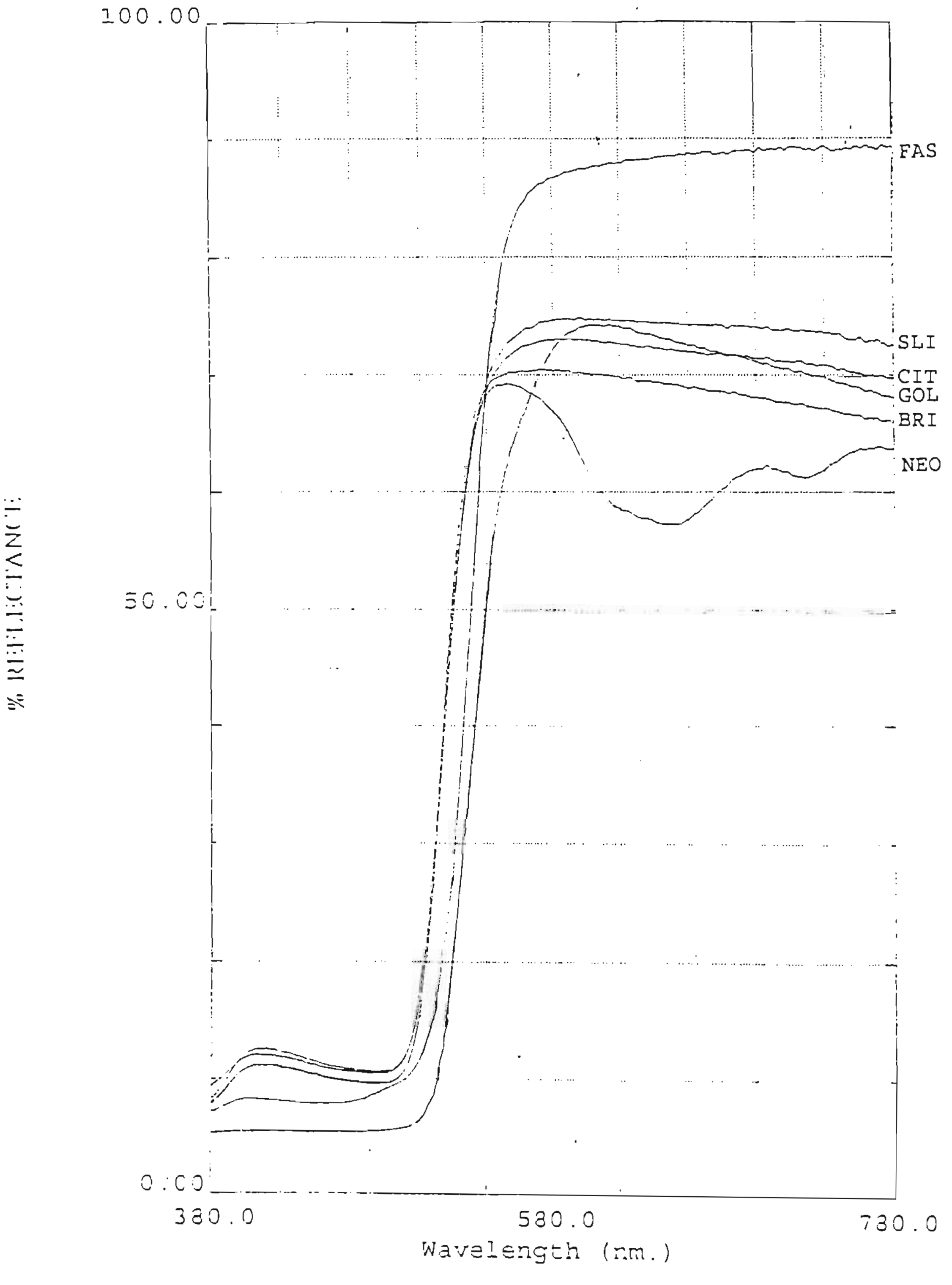

Figure 11. Spectral reflectance curves of the different hues of yellow used to test the phototactic response of *L. laevigatum*

Table 25. Wavelengths of various hues of yellow, and their percentage reflectance.

HUE	WAVELENGTH (nm)	REFLECTANCE (%)
'Fasson' yellow	565	89
'Citrus'	550	71
'Slicker'	550	75
'Bright lights'	545	68
'Neon light'	551	69
'Golden yellow'	596	73

3.5.3.2 ANOVA

An ANOVA was done comparing the different hues of yellow at the two sites (Table 26). The results from this illustrated that there were no significant differences between the hues. In addition to this, the hue by site interaction was not significant, showing that the characteristics of the sites did not affect the insects response to hue.

Table 26. ANOVA comparing different hues of yellow for the capture of adult wattle mirids at the two sites over four weeks.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F.R.	Prob.	Sig.
HUE	5	3.27	0.653	1.57	$P=0.170$	ns
SITE	1	19.4	19.4	46.6	$P<0.001$	***
HUE X SITE	5	1.95	0.389	0.930	$P=0.459$	ns
ERROR	228	95.0	0.417			
TOTAL	239	120				

3.5.3.3 Cost analysis

Statistically there was nothing separating the different hues from each other. Therefore, in order to make a practical recommendation to the forester, the cost of the different paints, and the cost of the 'Fasson' yellow sticker were calculated (Table 27).

Table 27. Comparison of prices for the different hues of yellow (July 1995)

HUES OF YELLOW	COST PER TRAP
Citrus, Slicker, Neon light, Bright lights (i.e. 'Dulux' paint)	R 0.17
Golden yellow (i.e. 'Decade' paint)	R 0.13
'Fasson' yellow sticker	R 1.86

These results indicated that the paints were far cheaper than the sticker, with 'Golden yellow' being the cheapest per trap. Prices were then recalculated (Table 28) and compared to the original price of the 'Coke' bottle trap, which was calculated in Chapter 2 (pg. 57). These prices were all based on the price of 'reject' 'Coke' bottles (R 0.74) purchased from 'Consol Plastics'.

Table 28. Comparison of final prices of the 'Coke' bottle trap using different coverings for the trap.

Type of covering	Price of 'Coke' bottle	Price of materials covering bottle	Total price
'Fasson' yellow "original trap"	R 0.74	R 1.86	R 2.60
'Dulux' paint	R 0.74	R 0.17	R 0.91
Golden yellow	R 0.74	R 0.13	R 0.87

If the 'Golden yellow' paint is used instead of the 'Fasson' sticker the price of the trap is reduced by R1.73 compared to the original price.

3.6 DISCUSSION

3.6.1 Choice of colour

The results from both experimental sites indicated that yellow caught a significantly higher mean number of wattle mirids than any of the other colours. Significant differences between colours were entirely due to yellow, and not because of differences between any of the other colours. In a preliminary study conducted by Atkinson and Stewart (1993), yellow was also found to be attractive to *L. laevigatum,* but significant differences could not be proved. When they compared different patterns using yellow, plain yellow was found to be significantly better than any other colour or pattern (Atkinson & Stewart 1993).

Results from this study are similar to those obtained from many other experiments. In a study on aphids, yellow water pan traps captured a significantly higher mean number of aphids, but the differences between the other colours were not significant (Boiteau 1990).

The yellow colour used in this experiment had a wavelength of 565 nm. In a similar experiment looking at colour preference of beet leafhopper, *Circulifer tenellus* (Baker), Meyerdirk and Oldfield (1985) also found that yellow with a dominant wavelength of 570 nm was significantly more attractive than the other colours. In another experiment comparing six colours, for their attraction to greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), a pest of tomato, the superior attraction of yellow over other colours was confirmed, the attraction to bright yellow traps was even more marked than attraction to the natural green leaves themselves (Vaishampayan *et al.* 1975). In a study on pear thrips, *Taeniothrips inconsequens* (Uzel), fluorescent yellow traps caught the most individuals, while dark blue and dark green traps caught the least (Coli *et al.* 1992). Yellow is also attractive to the citrus blackfly, *Aleurocanthus woglumi* Ashby (Hart *et al.* 1978), and, the citrus psyllid, *Trioza erytreae* (Del Fuerico), (Samways 1987).

Many species of phytophagous insects use visual cues, particularly colour, to locate hosts, or differentiate among plant species (Prokopy & Owens 1983). Leaves reflect most light in the 500-600 nm (peak 550 nm) range (Prokopy & Owens 1983). The biological basis of the observed response of *L. laevigatum* may be that yellow is the most intensely reflective colour in that part of the spectrum. The green colour used in the experiment also had a wavelength within this range, but only had a reflectance of 35.4% compared to the yellow with a reflectance of 89%. It appears therefore, that yellow is acting as a "supernormal" stimulus mimic of wattle foliage, which is highly attractive to *L. laevigatum*.

3.6.2 Choice of hue

The results indicated that *L. laevigatum* reacts equally to all hues of yellow between 545 nm and 596 nm. In a similar experiment testing the attractiveness of three different hues of yellow to the beet leafhopper, *Circulifer tenellus* (Baker), results showed that there were no significant differences between the different hues (Meyerdirk & Oldfield 1985). In another study testing the effect of trap colour on capture of adult pear thrips, *Taeniothrips* *inconsequens*, results indicated that, while fluorescent yellow was the most attractive hue, it was not statistically different compared with yellow, red or non-UV white (Coli *et al.* 1992). Similar results were obtained by Samways (1986) on the citrus pest *Scirtothrips aurantii* Faure. He tested four different hues of yellow for their attractiveness, all four colours were more attractive than the clear coloured controls, but the differences between the hues were only significant at the 10% level.

The choice of hue cannot be made on statistical grounds. The aim of the study was to produce a practical trap which was cheap, effective and reliable. All hues were equally reliable, but the paints were far cheaper than the 'Fasson' stickers, and the 'Golden yellow' was the cheapest of the paints, at current prices. In a preliminary study by Atkinson and Stewart (1993) yellow paints were found to be unattractive or even repellent to *L. laevigatum*. This may have been because the paint was on the outside of their trap. In this experiment the paint was on the inside of the 'Coke' bottle trap, and was not found to repel the insect.

Paints may fade with time. Time constraints of this study did not permit this to be tested, and it may be useful for future studies to investigate if certain paints last longer than others.

3.7 CONCLUSIONS

3.7.1 Suggestions for trap colour

L. laevigatum is a yellow-sensitive species, with the highest over-all catch on yellow traps, making this the recommended trap colour.

3.7.2 Suggestions for trap hue

As there were no significant differences between *L. laevigatum* response to hues, and as 'Fasson' stickers are more expensive per trap than paints, it is recommended that the forester use a yellow paint for the trap, preferably 'Golden yellow' (Decade paint: Code: SGE 08*B49) which was the cheapest one tested.

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CHAPTER 4

CHOICE OF TRAP HEIGHT

SUMMARY

The aim here was to ascertain whether *Lygidolon laevigatum* showed a stronger positive taxis to a particular height of yellow sticky trap. The traps were cylindrical plastic traps, constructed from 2 litre plastic 'Coke' bottles. The heights were chosen to be practical and easy to reach: and were at heights 0.5 m, 1.0 m, 1.5 m and 2.0 m. The results showed that the 2.0 m trap was the most effective. *L. laevigatum* attacks wattle trees of heights between 0.3 m and 5.0 m. If the trap is placed too low, it is outgrown by the fast-growing wattle tree. However, placing the trap at heights above 2.0 m makes it impractical. Therefore, the best height for the trap is 2.0 m.

4.1 INTRODUCTION

A number of studies have found that most insect pest species respond differently to different heights of traps. Boivin *et al.* (1982) determined the optimal height of traps for the capture of phytophagous mirids in an apple orchard. They found that different species of mirid responded differently to different heights. They tested three heights 0.5 m, 1.5 m and 2.5 m. The sticky traps set at 0.5 m were too low to capture one of the species *Campylomma verbasci* (Meyer). However, there were no significant differences between the three heights for the capture of *Lygocoris communis* (Knight). For *Lygus lineolaris* (Palisot de Beauvois), the sticky traps performed best at a height of 0.5 m.

Other experiments have found that some pest species are attracted to traps placed at ground level, these include: the tobacco whitefly, *Bemisia tabaci* (Gennadius) (Gerling & Horowitz 1984), the beet leafhopper, *Circulifer tenellus* (Baker) (Meyerdirk & Oldfield 1985), and, the onion fly, *Delia antiqua* (Meigen), (Vernon *et al.* 1989). Other pest species are attracted to taller traps, for example, the citrus thrips, *Scirtothrips citri* (Moulton), which is attracted to tall traps at a height of 2.7 m (Beavers *et al.* 1971).

Lygidolon laevigatum adults readily take flight. This fact makes them amenable to capture on sticky traps. In 1970, Connell attempted to determine whether *L. laevigatum* adults were attracted to different heights of traps, but other activities prevented the experiment from being properly controlled, so it was abandoned. In the preliminary study conducted by Atkinson and Stewart (1993), testing two different trap heights, *L. Laevigatum*, was found to be attracted to tall traps placed at a height of 1.8 m.

The aim of this study was to determine the optimum height for the cylindrical plastic sticky trap which captured *L. laevigatum*.

4.2 STUDY SITE

A single site was chosen at the Mondi plantation, "Mountain Home", in Hilton (29°33S 30°17E; elevation 1094 m). The site had a medium infestation at the start of the experiment, with about four adult wattle mirids per tree. The trees were about one year old, and were approximately 3.0 m tall.

4.3 MATERIALS AND METHODS

The experiment was based on a randomised design, as already explained in Chapter 2 (pg. 28) and for the same reasons. Sticky traps constructed from cylindrical plastic 'Coke' bottles were used, for the reasons explained in the second chapter (Pg. 65). The experiment continued for four weeks, from the 15th May to 5th June 1995.

The four different heights chosen were: 0.5 m, 1.0 m, 1.5 m, and 2.0 m. The heights were chosen to be practical, so that the forester could reach them with relative ease. Each of the heights was replicated 10 times. Resulting in a total of 40 traps at the site.

The experiment on colour had indicated that yellow was the most attractive colour for capture of *L. laevigatum* (Pg. 94). However, the previous experiment on hue (Chapter 3 pg. 76) was still continuing and the results had not been analyzed, therefore, to standardise the experiment, the traps were covered with a 'Fasson' yellow sticker (as in Chapter 2, pg. 34). All the traps were covered with a layer of clingfilm ('Gladwrap'), and coated with the sticky substance 'Flytac'. The traps were attached to wooden poles and planted between the rows to the final four heights. The traps were collected weekly, for four weeks, and on recovery, the traps were covered with another layer of clingfilm, sealing the flying insects between the two layers. The sample was then taken back to the laboratory where the adult wattle mirids were counted.

4.4 STATISTICAL METHODS

A suitable transformation for wattle mirids was calculated using Taylor's (1961) power law (pg. 37). These data were transformed using the same square root plus 0.5 transformation.

ANOVA was used for analysis, for the same reasons as explained in Chapter 2 (pg. 38). The computer program Genstat was used to calculate the ANOVA. Significant differences between the means were determined using the Least Significant Difference test (LSD). The LSD test was explained in Chapter 2 (pg. 38), and was used in this experiment for the same reasons.

4.5 RESULTS

4.5.1 Abbreviations used

The abbreviations used in the ANOVA and LSD tables are the same as those used in Chapter 2 (Pg. 40). The LSD table is also constructed in the same manner as the LSD tables in Chapter 2 (Pg. 40).

4.5.2 ANOVA

An ANOVA was calculated for the different heights, pooling the adults (Table 29).

Table 29. ANOVA comparing different heights for the capture of adult wattle mirids over four weeks at Hilton.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F.R.	Prob.	Sig.
HEIGHT	3	16.0	5.34	11.2	$P < 0.001$	***
ERROR	156	74.5	0.478			
TOTAL	159	90.6				

These results indicated that there were highly significant differences between the heights.

4.5.3 LSD test

To discover where the differences between heights lay, the means and standard errors (S.E.) were calculated (Fig. 12) and from this the LSD (Table 30) could be calculated.

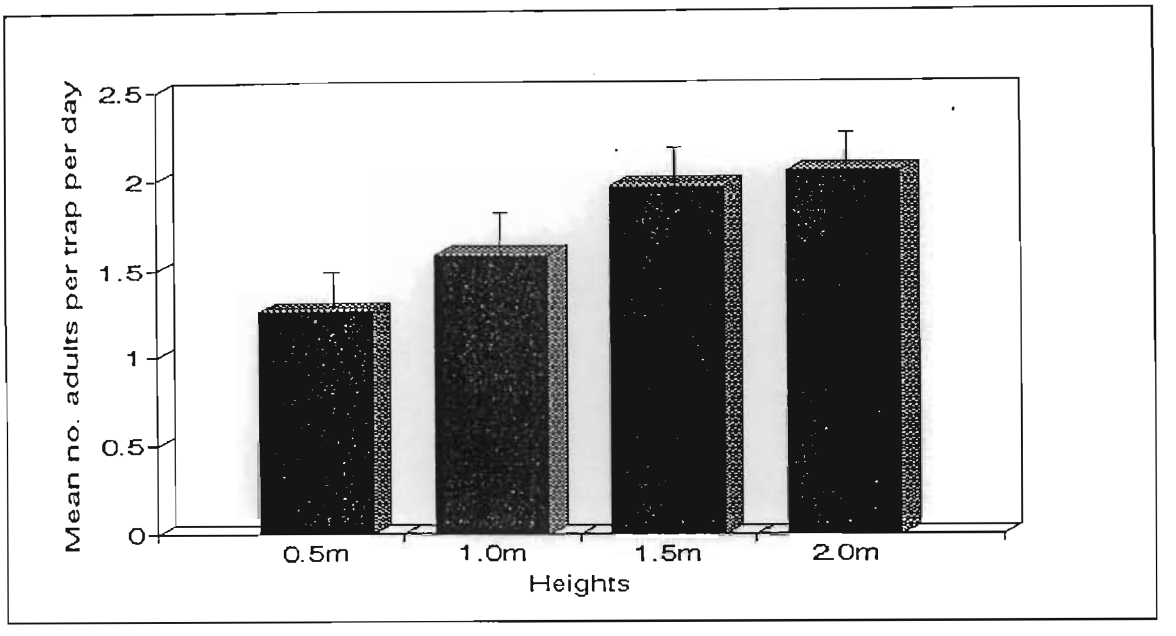

Figure 12. Mean (±1 S.E.) number of adult wattle mirids caught per trap per day on different heights of sticky trap

These results showed that the 2.0 m trap caught a higher mean number of individuals than the other traps. This was followed by the 1.5 m trap, then by the 1.0 m trap and finally by the 0.5 m trap which caught the least number of individuals.

Table 30. Least significant differences between number of adult wattle mirids caught at different heights.

0.5 vs 1.0	0.5 vs 1.5	0.5 vs 2.0	1.0 vs 1.5	1.0 vs 2.0	1.5 vs 2.0	ORDER
-2.11 **	-4.58 **	-5.12 **	-2.47 **	-3.01 **	-0.540 **	2.0m 1.5m 1.0m 0.5m

5% probability level = 0.30

1% probability level = 0.40

These results indicated that there were highly significant differences between all the traps, with the 2.0 m trap catching the highest mean, followed by the 1.5 m, the 1.0 m and finally by the 0.5 m traps.

4.6 DISCUSSION

4.6.1 Feeding behaviour of *Lygidolon laevigatum*

Nymphs and adults of *L. laevigatum* feed on the pinnules of young mature, or developing leaves, the tissues of tiny developing leaves and the meristematic tissue of terminal buds (Connell 1970). The eggs are laid on the tender terminal shoots of actively flushing young wattle trees (Connell 1970). These areas are the natural feeding places of the adults, and both the adults and nymphs appear unable to feed on the more mature foliage, or terminals which are not in a condition of flush (Connell 1970). This means that the adults are found near the top of the canopy where the trees are in a state of flush.

The results from this experiment showed that the wattle mirids were attracted to the tallest traps, but this is possibly a function of the height of the tree, with the adults being situated in the top of the tree canopy. *L. laevigatum* damages young wattle trees in their first two years of growth, when the trees have a height range of 0.3 m to about 5.0 m (Govender & Fletcher 1994).

4.6.2 Other studies

Beavers *et al.* (1971) carried out a similar experiment looking at the colour and height preference of the citrus thrips, *Scirtothrips citri* (Moulton), in a naval orange orchard. They tested three different heights: 0.9 m, 1.8 m and 2.7 m. Traps placed at 2.7 m above the ground caught significantly more thrips individuals, than those placed at 0.9 or 1.8 m above the ground. They suggested that this response may have occurred because the more succulent foliage in the upper portions of the trees was preferred by the citrus thrips for feeding and oviposition, or because of a negative geotactic, or positive phototactic response which had not been differentiated.

In another experiment, testing the effect of trap height on capture of sharpnosed leafhoppers, *Scaphytopius magdalensis* (Provancher), in blueberry fields (Meyer & Colvin 1985), results indicated that there was a highly significant relationship between bush height and number of leafhoppers collected at different distances from the ground. Another experiment on flight behaviour of the green lacewing, *Chrysopa carnea* Stephens, found that newly emerged, unfed, lacewings flew downwind at heights above 3.0 m, and were not attracted to food sources (Duelli 1980). In comparison, older specimens which were well-fed, also flew downwind, but mostly at a height of less than 3.0 m, and after passing food they turned upwind and were attracted to the food (Duelli 1980). The results from these experiments appear to confirm that some species are attracted to traps placed close to their feeding areas.

4.6.3 Suggestions for further study

In this study *L. laevigatum* was significantly attracted to traps placed 2.0 m above the ground rather than at lower heights. However, this experiment took place in a plantation where the trees were approximately 1 year old, and at about 3.0 m tall. In plantations where the wattle trees are either shorter or taller that 3.0 m, the response of the wattle mirid may not be the same. It may therefore be necessary to repeat this experiment in plantations where the trees are of different heights.

4.7 CONCLUSIONS

L. laevigatum attacks trees between about 0.3 m and 5.0 m. It is suggested that because the adult wattle mirids feed in the top of the canopy they will be attracted to traps which are placed close to the top. However, in the younger plantations where the trees are short, placing the trap level with the canopy of the tree, means that the trap will soon be outgrown by the fast-growing wattle tree. Furthermore, as wattle mirid catches are lowest at a low trap height, it is better to ensure that the trap is placed above the tree canopy. There is, however, also a practical limitation. Traps at a 5.0 m height could not be reached without a ladder, which would be quite impractical. So, the best compromise is to place the trap as high as possible, but which can be easily reached without a ladder: the 2.0 m height is this good compromise.

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CHAPTER 5

ESTIMATION OF ECONOMIC THRESHOLDS

SUMMARY

The aim here was to determine an economic threshold for *Lygidolon laevigatum* using the cylindrical, yellow, 'Coke' bottle trap. Results from the regression analysis suggested that eight adult wattle mirids per trap per week was the threshold during the summer months. Results also indicated that eight traps placed diagonally across a one hectare plantation would adequately assess spatial population distribution.

5.1 INTRODUCTION

The concepts of economic injury and threshold levels for pest species are key components of integrated pest management (Mailloux & Bostanian 1988), and these concepts are the backbone of any sound pest management programme (Dent 1991). The economic threshold is defined as the pest density at which control measures should be applied, to prevent an increasing pest population from reaching the economic injury level (Stern *et al.* 1959; Pfadt 1985). The economic injury level, is the lowest pest population level at which economic damage begins to occur (Stern *et al.* 1959; Pfadt 1985).

One of the key problems in developing an economic threshold is to determine a quantitative relationship between pest density and crop damage (Mailloux & Bostanian 1988). The damage to the crop results from the feeding activities of the pest, and to a lesser extent its oviposition processes (Ruesink & Kogan 1975). The extent of the damage depends on a number of environmental factors, such as weather and soil conditions, and physiological factors of the tree, such as nutrition (Watson *et al.* 1976). The economic injury levels are not static, and vary from one region to another, and from one year to the next, as the value of the crop, and the cost of the control measures, change (Ruesink & Kogan 1975). Many kinds of traps have been used to sample insects, and can be of great value in surveying for the presence and magnitude of infestation of ceratin pest species (Stern 1973).

Very little effort has been put into the determination of an economic threshold for *L. laevigatum*. As a result, pesticides can often be applied as a routine preventative measure, irrespective of whether the pest is present or not. Many problems can arise following pesticide application: a rapid resurgence of the pest may occur, or a secondary pest may be promoted to a major pest status (Stern 1973). Pesticide applications for the control of *L. laevigatum* are often unnecessary. This is because the economic threshold has not been defined. The failure of foresters to notice the presence of the wattle mirid before the onset of economic damage, makes it necessary to develop a monitoring system so that the pest population is under constant surveillance. It is equally important that this monitoring system be given an economic threshold value so that the forester has sufficient time to implement control measures.

The objectives of this chapter were: 1) to attempt to define an economic threshold for the 'Coke' bottle trap, 2) to determine approximate trap density, and, 3) to decide on trap location in the plantation. A study on spatial population distribution, concentrating on the numbers of individuals caught throughout the study, and the sex ratio of adult *L. laevigatum* was also conducted.

5.2 STUDY SITES

5.2.1 Sites used for determination of economic threshold

The study was based on the data collected during the first experiment. Therefore the sites were the same as those that were mentioned in Chapter 2 (Pg. 27).

5.2.2 Site used for the determination of trap density and the study of spatial population distribution of the wattle mirid

The study was based on the data collected during the experiment looking at hue, Chapter 3 (Pg. 77). Since there were no statistical differences between the hues (pg. 94), each of the traps was assumed to be acting equally and therefore could be used for the determination of trap density. The traps were also used for the study of the spatial population distribution of *L. laevigatum*.

There were statistical differences between the two sites. To determine trap density in the plantation, the site with the slightly lower infestation (Richmond) was chosen. The reason for this choice was to obtain results based on a conservative estimate of infestation. To study spatial population variation in the plantation, both the sites were used. This would indicate whether there were any site differences in infestation patterns.

5.2.3 Site for study of temporal population variability

The study site was at the Bloemendal Experiment Station, about 14 km North-east of Pietermaritzburg (29°32'S 30°28'E; elevation 860 m).

Once the first experiment, (Chapter 2) was completed, a new site within the same plantation was chosen for the continuation of the monitoring of the population variability. A new site had be used because by the end of the first experiment the trees at the first site were too tall for wattle mirid infestation.

5.3 MATERIALS AND METHODS

5.3.1 Economic threshold

During the time that the first experiment (Chapter 2) was conducted, an estimation of damage caused by the wattle mirid was made. The type of damage caused by the wattle mirid can be divided into five broad categories (See pgs 6 & 7, and plates 2a - 2d):

0) No damage

1) Pinnule feeding

2) Feeding on the apical bud

3) Multiple branching

4) Witches broom effect and pinnule loss

Each day when samples were collected from the field, three trees within each plot were randomly selected using a random numbers table (Steel & Torrie 1981), and rated for damage on a scale of 0 (no damage) to 4 (witches broom and pinnule loss).

In addition to the estimate of damage, sweep net samples were collected from trees within the site. The sweep net samples were taken randomly from six trees within the plot, and each tree was swept six times. The samples were stored in 70% ethyl alcohol, and taken back to the laboratory where the adult wattle mirids could be counted.

5.3.2 Trap density and spatial population distribution

The materials and methods were the same as those mentioned in Chapter 3 (Pg. 77).

5.3.3 Temporal population variability

The wattle mirid population was monitored throughout the entire study, beginning in March 1994, and ending in May 1995. Two different areas of the same study site were used. The first area was used from May 1994 to September 1994, and the second area was used from November 1994 to May 1995. The results from the first area (Chapter 2, Pg. 64) were used as they had indicated that the sweep net was the best instantaneous method for the capture of adults and the beating tray was the best instantaneous method for the capture of nymphal instars. The yellow 'Coke' bottle trap was the best cumulative method (Chapter 2, pg. 65). These methods were used again in the second area (Nov 1994 - May 1995) for monitoring the population variability. The samples of adults were also sexed. Rainfall data for Bloemendal were also obtained.

5.4 STATISTICAL METHODS

5.4.1 Economic threshold - Regression analysis

To assess the economic threshold, a regression analysis was performed (see: Le Clerg 1971; Thistlewood *et al* 1989; Mailloux & Bostanian 1988; Du Toit 1986; Archer & Bynum 1990).

Regression analysis examines the relationship between two variables and provides an equation relating one variable to another (Elliott 1977). It allows the data to be summarised and quantifies the nature and strength of the relationships among variables. Regression analysis also allows the prediction of new values for the dependent variable based on the observed relationships (Steel & Torrie 1981).

Linear regression describes the average change in a dependent variable (y), for a unit change in an independent variable (x) (Steel & Torrie 1981). The linear regression analysis should be confined to problems where it is desired to predict the value of the dependent variable, from knowledge of the value of the independent variable (Alder & Roessler 1977). In regressing y on x, it is assumed that x has been measured with minimum error and hence the observed scatter can be attributed to y (Steel & Torrie 1981). The regression model further assumes that the errors are the same throughout the range of x and are independent (Steel & Torrie 1981). Linear regression was calculated using the computer program Statgraphics.

5.4.2. Trap density - Bootstrap

A statistical technique known as bootstrapping was used for analysis. Bootstrap procedures have proved themselves extremely powerful in generating confidence intervals (Efron 1982). It is a non-parametric method which does not rely on a normal distribution (Efron 1982). Therefore, no transformation was necessary.

The method was calculated as follows: The results from one site (i.e. 30 traps) were used. Samples were drawn from this total, with replacement, a large number of times. Sampling with replacement means that the bootstrap sample may include some traps more than once and others not at all (Buonaccorsi & Liebhold 1988). For this experiment, 10 000 bootstrap samples were taken using different numbers of traps. The numbers of traps used were: 2, 4, 5, 6, 8, 10, 12, 14, and 15 traps. For example, if 10 traps were used, the bootstrap sample found the mean number of adults caught on 10 traps, and repeated the process 10 000 times.

The aim here was to find the minimum number of traps required to make population counts of adults with acceptable precision. This can be determined by calculating the most stable mean (or the one with the smallest range between the upper and lower 95% confidence interval). The number of traps had to be practical, so it was decided to use a maximum of 15 traps, beyond which, expense and logistics became too great.

5.4.3 Temporal population variability - Correlation analysis

Correlation is a measure of the degree to which variables vary together (Steel & Torrie 1981). The closer the correlation coefficient lies to one, the better the correlation (Alder & Roessler 1977). A correlation analysis was carried out using the computer program Statgraphics, to test whether the total number of individuals caught with the different sampling methods was correlated to rainfall.

5.4.3.1 Sex-ratio - Chi-squared analysis

The Chi-squared test is defined as the sum of squares of independent normally distributed variables with zero mean and unit variance (Steel & Torrie 1981). The Chi-squared test was carried out on the raw data to test the null hypothesis that the sex ratio of the adults did not differ from the expected ratio of 1:1. The Chi-squared test is most commonly associated with enumeration data (Steel & Torrie 1981), and is often used when the data take the form of counts or proportions (Clarke 1987). Enumeration data generally involve discrete variables; they consist of the numbers of individuals falling into well defined classes (Steel & Torrie 1981). In this case, the population of *L. laevigatum* was sampled and the numbers of males and females in the sample were observed. The expected values were calculated as 1:1 ratios of the observed values.

5.5 RESULTS

5.5.1 Economic threshold

The data on the damage estimates were pooled and analyzed using the linear regression. The results indicated that the correlation co-efficients lay very close to one, showing that there was a strong relationship between the dependent (damage) and the independent (number of individuals) variables. The regression was, however, negative, and this made the model very difficult to use for making predictions, and it was not used for the determination of the economic threshold.

Results from Chapter 2 (pg. 64) had shown that the sweep net gave an accurate estimation of the number of adults on the tree. Connell (1970) stated that counts from a sweep net averaging 6-10 adults per tree, were high, and resulted in multiple branching and witches broom. Therefore, it was possible to use the sweep net results to predict the type of damage caused. These results could then be used to determine the number of insects caught on the 'Coke' bottle trap.

A regression analysis (Table 31) was carried out in which the number of adults per 'Coke' bottle trap per day was used as the dependent variable (y), and the number of adults per tree (caught using the sweep net) was used as the independent variable (x). In other words, the number of insects caught on the trap was assumed to be dependent on the number of insects in the tree.

Table 31. Results from regression, using number of adult wattle mirids caught in sweep net (x) and number of adults caught on 'Coke' bottle (y)

CORRELATION COEFFICIENT	R-SQUARED	SIG. LEVEL	EQUATION $y = a + bx$
0.756	56.6%	$P < 0.001$	$y = 0.105 + 0.177x$

The results from the ANOVA indicated that the linear regression model was a good fit. This is indicated by the high level of significance. The R-squared value was relatively high, and indicated that 56.6% of the variation in the trap catches, could be explained by variation in the sweep net catches. The results also indicated that there was a close correlation between the catches made with the sweep net and those made with the 'Coke' bottle.

These results from the regression analysis were used for prediction purposes. Connell (1970) stated that between 6 and 10 adults per tree caused economic damage. The lowest limit of 6 adults per tree was used, from this, the number of insects caught on the 'Coke' bottle trap could be calculated.

5.5.1.1 Calculation of economic threshold for the 'Coke' bottle trap

EQUATION ($y = a + bx$)

Where y is the number of adult wattle mirids caught on the trap per day and x is the number of insects caught from one tree with the sweep net. When the sweep net caught six adults (i.e. $x = 6$):

$$y = 0.105 + 0.177(6) = 1.167$$

The y value is the prediction of the number of adults caught per trap per day. The wattle mirid population can increase relatively rapidly (Connell 1970), making it necessary for the traps to be checked on a weekly basis. Therefore in one week (i.e. 7 days):

$y = 1.167(7) = 8.169$

These results indicated that if the trap was left out for one week, and if eight adults were caught on the trap, then, control measures needed to be taken to prevent the population exceeding the economic threshold.

5.5.2 Trap density

The computer program Resampling stats was used for the bootstrap, and the results were tabulated (Table 32).

The means became more and more stable the greater the number of traps used. If less than eight traps were used, the means differed by more than one wattle mirid per trap. When looking at the economic threshold, a difference of one adult per trap is significant.

Table 32. Results from bootstrap procedure, for trap density in a one hectare plot.

NUMBER OF TRAPS	CONFIDENCE INTERVAL (95%)	DIFFERENCE
2 TRAPS	1.000 - 2.855	1.855
4 TRAPS	1.215 - 2.605	1.390
5 TRAPS	1.292 - 2.486	1.194
6 TRAPS	1.333 - 2.428	1.095
8 TRAPS	1.410 - 2.374	0.964
10 TRAPS	1.460 - 2.317	0.857
12 TRAPS	1.490 - 2.285	0.795
14 TRAPS	1.519 - 2.254	0.735
15 TRAPS	1.533 - 2.238	0.705

5.5.3 Spatial population distribution and location of traps in the plantation

The results from the spatial population distribution are graphically represented (Figs 13 & 14). The asterisks with numbers next to them indicate the number of adults caught at that trap location. For example, in Figure 13, trap A1 caught 19 adult wattle mirids.

The results from each of the sites were kept separate. The graphs were constructed using the computer programme Surfer. These results were used to determine the location of the traps in the plantation.

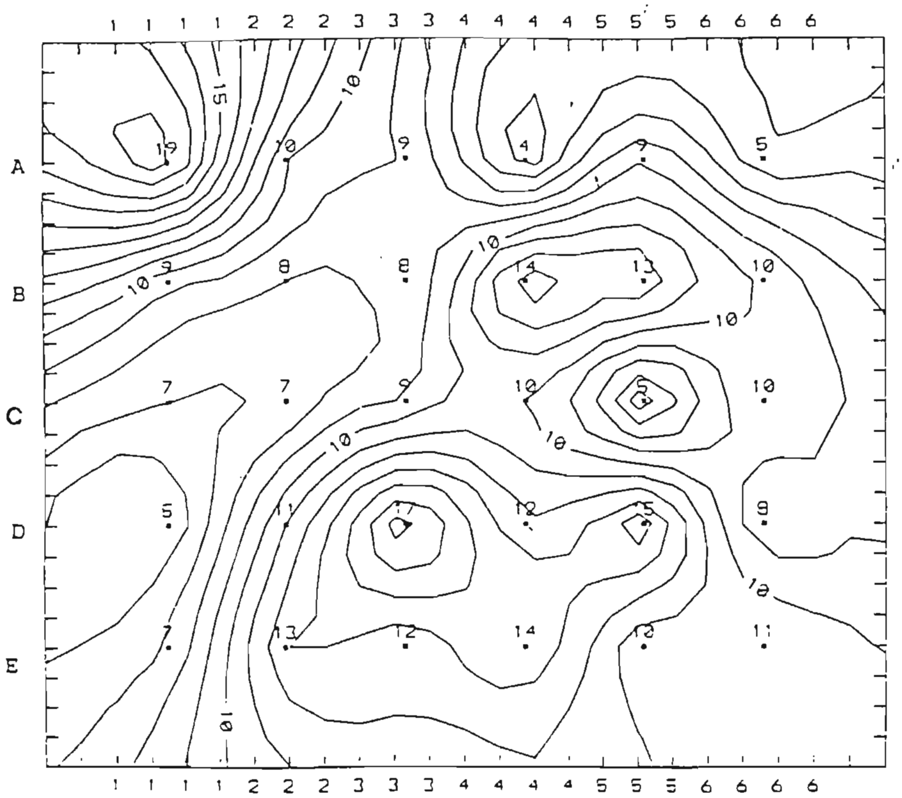

Figure 13: Total number of adults caught on each trap at Hilton

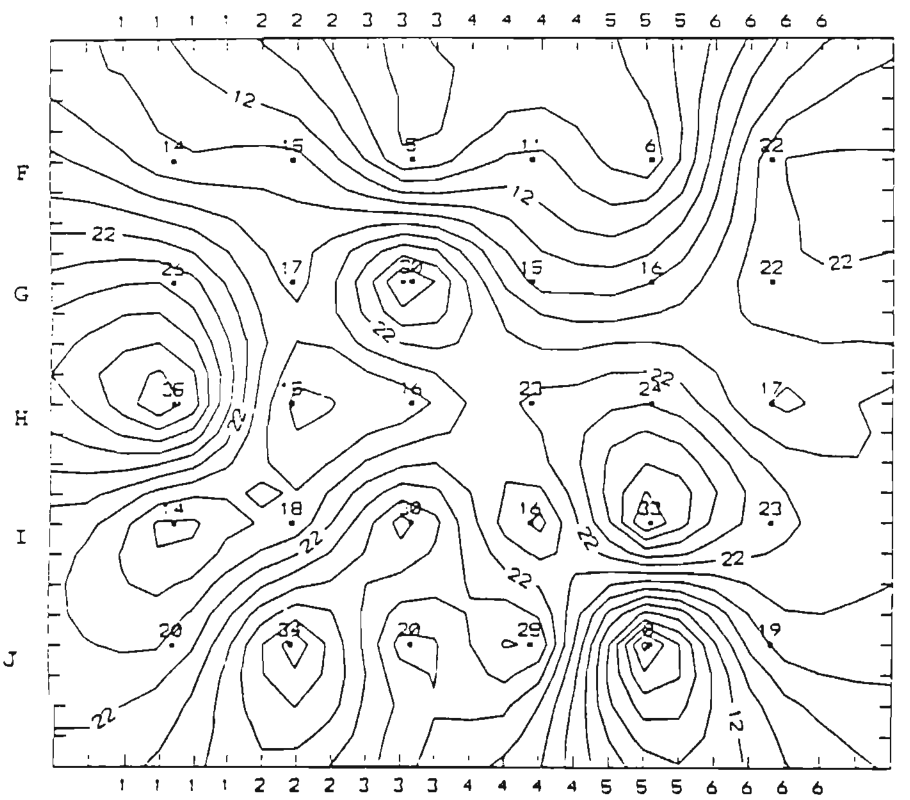

Figure 14: Total number of adults caught on each trap at Richmond

The results indicated that the infestation was not uniform, and that there were no obvious spatial patterns in the distribution of the adults.

5.5.4 Temporal population variability

The results from the temporal population variability are graphically represented (Figs 15-17). The raw data for the total number of adults have been used for all the sampling methods. Data for the adults were also analyzed separately for males and females. The rainfall data were also obtained (Fig. 18).

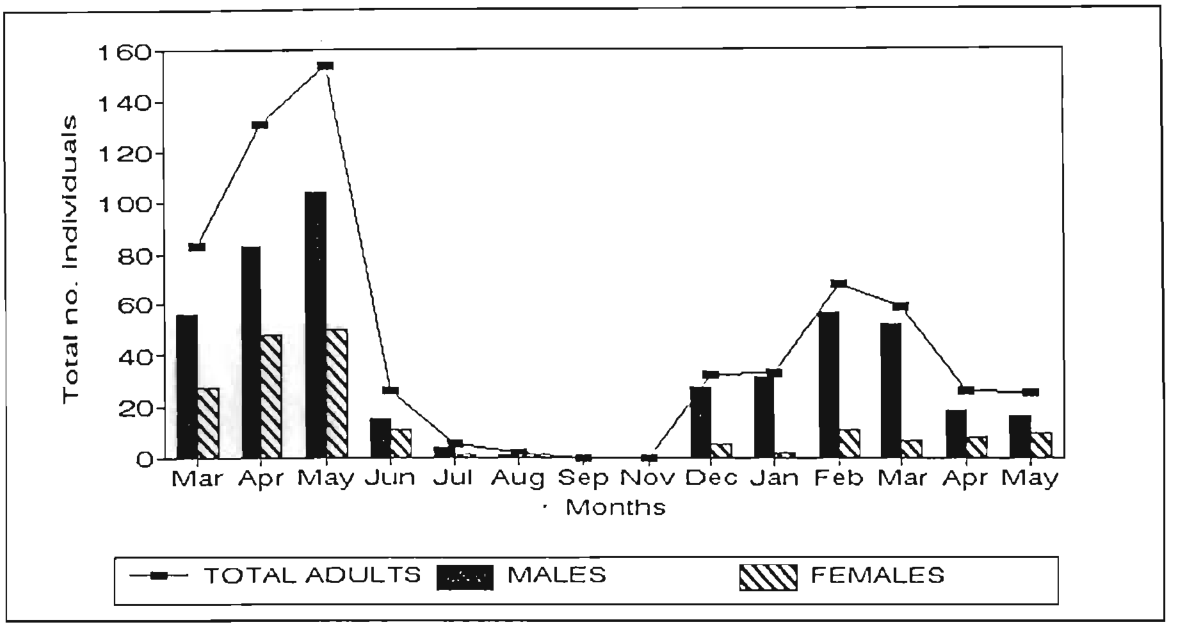

Figure 15. Total number of adult wattle mirids caught on 'Coke' bottle trap at Bloemendal Experiment Station throughout sampling period (March 1994 - May 1995).

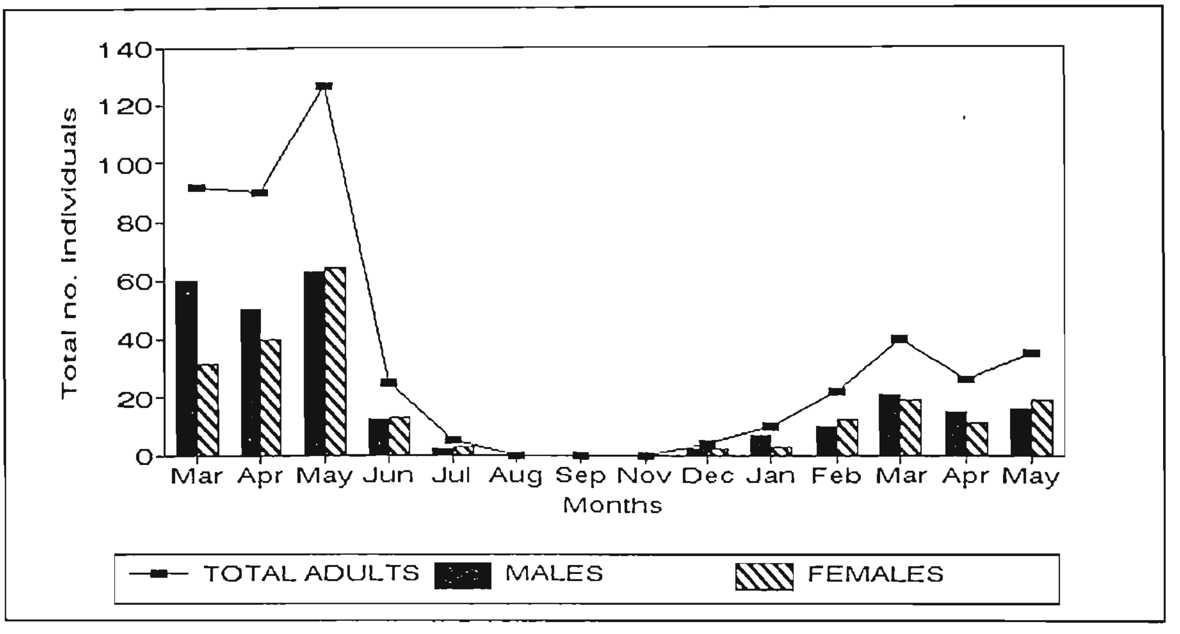

Figure 16. Total number of adult wattle mirids caught with sweep net at Bloemendal Experiment Station throughout sampling period (March 1994 - May 1995).

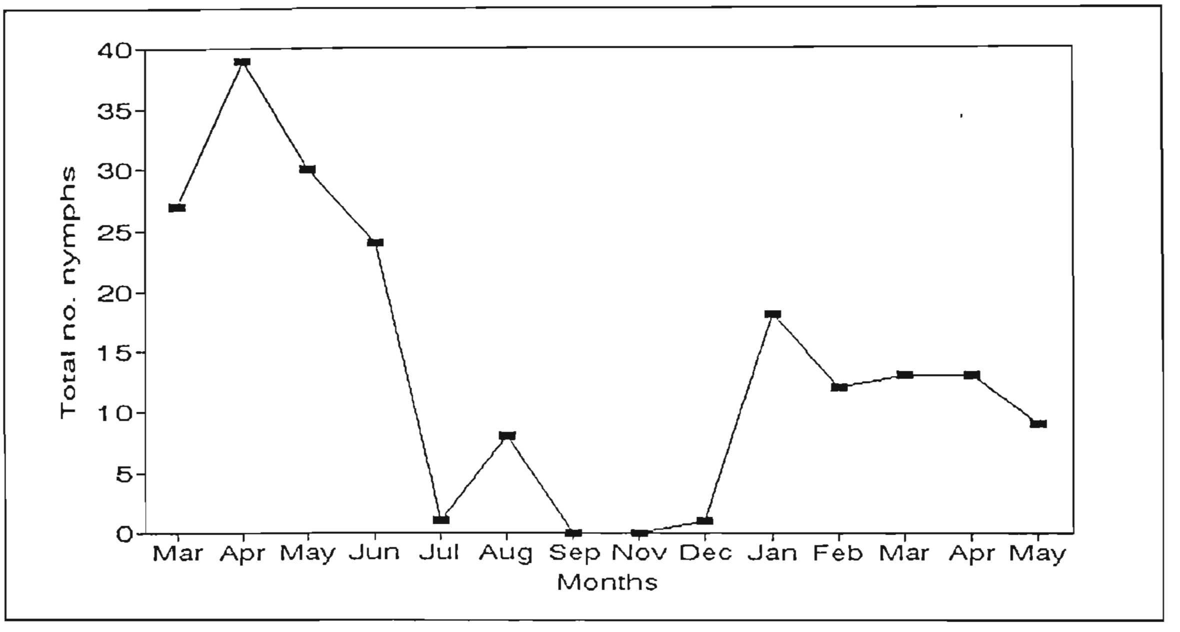

Figure 17. Total number of wattle mirid nymphs caught with beating tray at Bloemendal Experiment Station throughout sampling period (March 1994 - May 1995).

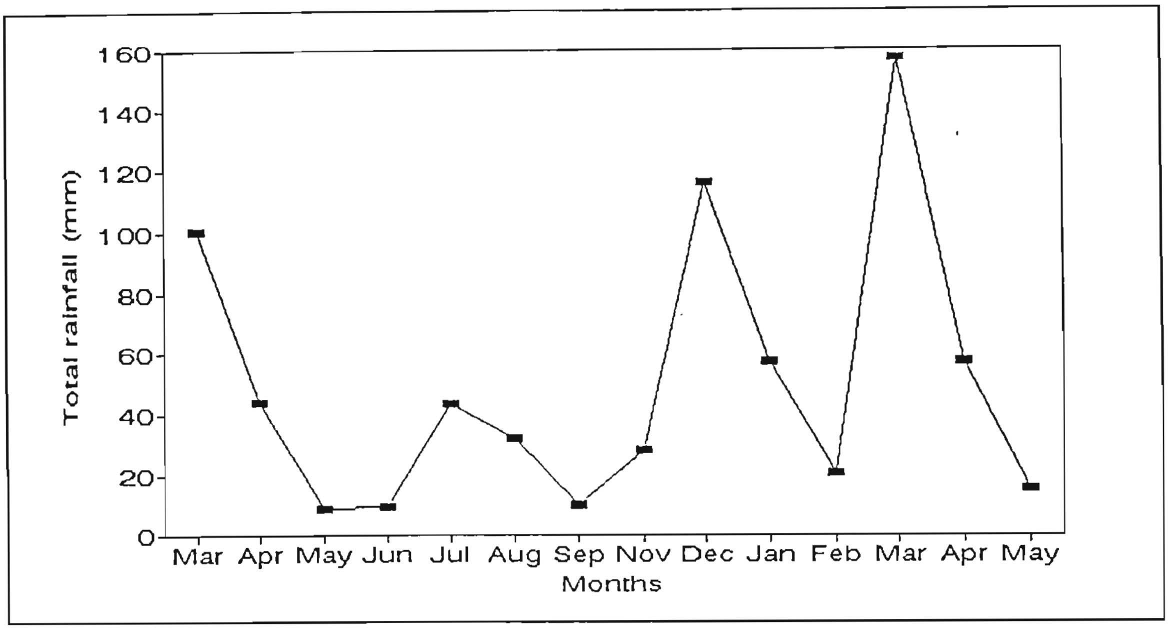

Figure 18. Total rainfall at Bloemendal Experiment Station throughout the sampling period (March 1994 - May 1995).

These results indicated that the infestation during the first year was much higher than during the following year, and that the infestation levels were higher during the rainy season. Both adults and the nymphs follow this pattern.

The correlation analysis (Table 33) indicated that the changes in the population levels were closely correlated with the rainfall pattern.

Table 33. Correlation analysis comparing rainfall patterns with numbers of adult wattle mirids caught using sweep net and 'Coke' bottle trap, and numbers of wattle mirid nymphs caught using beating tray

	SWEEP NET	'COKE' BOTTLE	BEATING TRAY
CORRELATION COEFFICIENT	0.9079	0.8129	0.9251

5.5.4.1 Sex Ratio

The results from the adults caught with the sweep net and the 'Coke' bottle trap were analysed using the Chi-squared test, to test whether the sex-ratio differed from the expected 1:1 ratio. The results from those months when the sex-ratio differed from the expected 1:1 ratio were tabulated (Tables 34 & 35).

Table 34. Significant Chi-squared results from sex-ratio of adult wattle mirids caught with the sweep net.

MONTH	CHI-SQUARED VALUE	PROBABILITY LEVEL
March 1994	8.522	$P < 0.001$

These results show that the sweep-net caught an equal number of males and females throughout the experiment, except during March 1994, when the males dominated the population.

Table 35. Significant Chi-squared results from sex-ratio of adult wattle mirids caught with the 'Coke' bottle trap.

MONTH	CHI-SQUARED VALUE	PROBABILITY LEVEL
March 1994	10.13	$P < 0.001$
April 1994	9.350	$P < 0.001$
May 1994	18.94	$P < 0.001$
December 1994	15.13	$P < 0.001$
January 1995	25.49	$P < 0.001$
February 1995	31.12	$P < 0.001$
March 1995	34.32	$P < 0.001$

These results showed that the 'Coke' bottle caught a significantly higher number of males than females. These results were more pronounced during the rainy season. During the winter months, the sex-ratio did not differ from the expected ratio of 1:1.

5.6 DISCUSSION

5.6.1 Estimation of the economic threshold

To calculate an economic threshold, it is necessary to take a wide variety of factors into consideration. There are four basic factors which determine the economic injury level, these include; 1) the cost of control, 2) the market value of the product, 3) pest damage, and 4) the response of the trees to damage (Brewer *et al.* 1994). The responses of the trees to insect damage are, in turn, determined by both physiological and environmental factors (Pfadt 1985).

Economic studies are more of a long term-project in a crop such as wattle. This study was short-term and could not take many of these factors into account. The study was a preliminary one which looked at the density of the pest and compared this to the value given by Connell (1970).

5.6.1.1. Effect of damage

The damage caused by the wattle mirids may be described as being cumulative. The regression, comparing numbers of adult wattle mirids with damage, was negative, this meant that with a high number of individuals, the damage was low. This at first, appears to make little sense, but was as a result of a lag in time. Early in the season, when the numbers of individuals were high, the plantation was still undamaged, and on the scale of damage from 0 to 4, the damage was between 0 and 1. The damage may be described as being cumulative. As populations of *L. laevigatum* increased, and feeding activity increased, the damage also increased. Towards the end of the season, when the damage was at its worst (ranked at 3 or 4), the wattle mirids had left the plantation in search of new undamaged trees. Other studies have also shown that correlations between population levels and plant damage are difficult to establish (Luckmann & Metcalf 1975).

The lag in time before the damage was noticed was very difficult to quantify, making it difficult to use the model for predictions. Time constraints made it impossible to test this lag. Therefore these data could not be used for predictive purposes.

5.6.1.2 Effect of number of insects on the tree

Connell (1970) stated that economic damage occurred when six adult wattle mirids were caught from a sweep net sample of one tree. Results from the regression analysis, comparing the number of adults caught on the tree to the number of adults caught on the trap, were useful for making predictions, and were used to determine the economic threshold. The threshold was found to be eight wattle mirids per trap per week. During the study, the numbers of adults caught on the 'Coke' bottle trap, at the beginning of the season, were found to approximate this, therefore the figure appeared to be a reasonable one.

For more precise estimations of the threshold, it is recommended that the forester check this figure against the number of adults in the tree. In other words, the trap would provide the forester with a warning that the pest population is increasing to the economic injury level, and this should be checked by taking sweep net samples from the trees in the plantation. If the forester finds that six adults are present in the tree, as well as finding eight adults on the trap in one week, action is required to prevent a further, damaging, increase in the population.

5.6.1.3 Further studies

The economic threshold requires some refinement. There were a number of things which could not be tested because of the logistic and time constraints of the study. It would be useful for future studies to look at some of these factors (see below).

5.6.1.3.1 Time lag between presence of *L. laevigatum* and the appearance of damage.

The lag in time between the presence of the wattle mirid and the appearance of damage needs to be quantified. To test this lag, the study needs to be conducted over several years. A number of environmental and physiological factors would need to be considered, since these would affect the number of wattle mirids and the damage caused. Some of the factors which would need to be considered include rainfall, temperature, soil conditions and different planting techniques.

5.6.1.3.2 Vector or not?

It has not been firmly established whether *L. laevigatum* is a vector, but evidence to date suggests that it is not. Feeding damage is probably mechanical (Connell 1970). However, continuous feeding by *L. laevigatum* also has a distinctly systemic toxic effect. The toxicity of the saliva causes the tree to shed its pinnules, while the stem and branches of the tree take on a dull grey-green colouring, often far from the points of feeding (Connell 1970). Before the economic threshold can be determined with any degree of confidence, it is necessary to test whether these effects are indeed produced by the toxic saliva, or whether *L. laevigatum* is the vector of an undescribed pathogen.

5.6.1.3.3 Loss in yield

A long-term study would be useful for determining the loss of yield caused by *L. laevigatum* attack. The study would need to be done from time of planting, until time of harvesting, which is normally a ten-year rotation (Sherry 1971). There are a number of other factors which can also affect yield, and require testing. These include weather conditions, site conditions, and, other insect pests and diseases. A number of different sites would need to be tested, and, the data would require regular updating, since the costs of control and the value of the product are constantly changing.

5.6.1.3.4 Adults or nymphs?

This experiment looked at the adult life-stages of *L. laevigatum*, and did not consider the nymphs. However, the results of Fletcher (1994) indicated that both life stages were equally implicated in the damage. It would be useful to determine an economic threshold for both the life stages, and to use this information in the development of a monitoring technique which takes both life-stages into consideration.

5.6.2 Estimation of trap density

Where the means obtained from the bootstrap sample differed by more than one wattle mirid, the traps were not providing an accurate estimate of numbers of individuals present in the plantation. A difference of one adult caught on a trap was important when considering the economic threshold. Using this, it was decided that eight traps was the number of traps required in a one hectare plantation.

These results were from an intensive experiment on a one hectare plot. It was not possible to say how accurate eight traps would be in a larger area. The traps should be acting independently from one another, and therefore, it is thought that eight traps would be accurate on all medium-sized plantations.

5.6.2.1 Further studies

Trap density could be tested in plantations of different sizes to test the accuracy of using eight traps in plantations of different sizes. Often, however, foresters will not consent to leaving a large area of their plantation untreated. Such a study would require extensive wattle plantations and the co-operation of the foresters.

5.6.3 Spatial population distribution and location of traps in plantation

Generally infestations are not uniform. Therefore, it is essential to take a sample that attempts to overcome this lack of uniformity (Watson *et al.* 1976).

The standard procedure for average-sized fields of crops such as cotton is to sample four areas, avoiding sides and edges, but noting insect activity at any point (Watson *et al.* 1976). In crops such as alfalfa, the sampler moves diagonally across the field (Watson *et al.* 1976). From studies of monitoring of *Delia antiqua* (Meigen) in onion fields, it appears that the best position for the traps is around the perimeter of the field (Vernon *et al.* 1989), which is also similar for the monitoring of carrot rust fly, *Psila rosae* Fabricius (Judd *et al.* 1985).

The most important consideration is good representation, or field coverage. Since there were no distinct spatial patterns in wattle mirid infestation, the traps could be placed randomly, or evenly in the plantation. A random design makes it very difficult to locate the traps, therefore it is suggested, for practical reasons, that the traps be placed evenly in the plantation, and to give good coverage of the plantation, a reasonable design for trapping *L. laevigatum* in black wattle would be to place the traps diagonally from one corner of the plantation to the opposite corner.

5.6.4 Temporal population variability

The most obvious factor arising from the monitoring of the population variability was that during the first season the infestation was high, and during the second season, the infestation was much lower. The reason for this difference was not clear. It is possible that the lack of pesticides, used in the plantation during the study, resulted in an increase of natural enemies, which kept the wattle mirid numbers low during the second season, but this was not quantified. Connell (1970), also found that numbers of adult wattle mirids during the second season of his study, were lower than during the first season. The explanation he gave was that there was possibly an increase in levels of parasitism, and a decrease in rainfall.

Rainfall is necessary to bring about a flush in young wattle trees, and this produces conditions which are particularly suitable for the wattle mirid to breed (Connell 1970). This explains why the populations were highest during the rainy seasons. During 1995, the rainfall was higher, yet the wattle mirid numbers were lower. Populations of *L. laevigatum* tend to increase after good rains. Connell (1970) found that rainfall patterns were not always positively correlated with wattle mirid numbers. Populations were sometimes low after the late appearance of rain. The explanation was that the late appearance of rain resulted in the delay of favourable conditions for the breeding of the wattle mirid, which kept the population at low levels. This may have also been the case in this study. The rainfall during January and February of 1995 was considerably lower than the rainfall during those months in the previous year. Increased rainfall during March and April 1995, may have been too late in the season to create favourable conditions for the population to increase to high numbers.

The beginning of the season appears to be the time of highest risk for wattle mirid outbreak. Infestations were highest during the early and late months of the year (December to May) when the rainfall was high and the trees were actively growing. During winter, the wattle mirid population decreased and remained at a very low level.

L. laevigatum has no true overwintering stage, and breeding continues throughout winter. The life-cycle of the wattle mirids is also longer during the winter months (Connell 1970), so the chance of a rapid build up in numbers during winter is low. This means that the foresters need to maintain a constant weekly surveillance of traps during the summer months, and possibly need only check the traps every two weeks in winter.

5.6.4.1 Sex-ratio

Male wattle mirids have a shorter life-span than that of the females, with the males dying soon after mating occurs (Connell 1970). The sex ratio averaged over time would be dependent on the replacement tempo of the two sexes. Therefore the ratio of offspring if equal, will produce a higher average figure for females because of their greater longevity. Connell (1970), also found that when breeding was checked by unfavourable tree conditions, the shorter life span of the males resulted in a rapid change in the sex ratio, with the females becoming predominant.

The results from the sweep net showed that for one month (March 1994), the males were significantly more dominant than the females. The samples collected during the winter months indicated that the females were dominant, supporting Connell's (1970) findings, but this domination was not statistically significant.

The results from the 'Coke' bottle trap indicated that the trap caught significantly more males than females during the rainy season. Once again, during the winter months, the females dominated, but this domination was not statistically significant. Male wattle mirids are far more active than females (Connell 1970). This means that they are more likely to be caught on the sticky traps, than the females, and in addition to this, the more active males take flight more readily than the females on the approach of the sweep net. This may explain why the 'Coke' bottle trap caught a significantly higher proportion of males in comparison with the sweep net.

In a similar study, looking at sex-ratios of *Lygus lineolaris* (Palisot de Beauvois), Stewart and Gaylor (1991), also found that the proportion of males caught on sticky traps was greater than in sweep samples. They suggested that this was because the males were better able to avoid capture by sweep net, or because the males flew more often than females. Males in many insect species are also more inclined to make frequent "trivial" flights compared to females (Dingle 1965, 1966; Johnson 1969). In an experiment testing sex-ratios of *Pholetsor ornigis* (Weed), a parasitoid of the spotted tentiform leafminer, *Phyllonorycter blancardella* (Fabricius), Trimble (1988), also found that yellow sticky traps were more effective for capturing males than females.

5.6.4.2 Further studies

Upsurges of wattle mirid populations could be predicted by rainfall and resultant growth flushes in wattle trees. The effective rainfall that is required to bring about growth flushes in young wattle trees is dependent on soil type, topography and surrounding vegetation (Connell 1970). It is therefore important that any assumptions made on correlations between rainfall, tree flushes and wattle mirid numbers, take into account the variables that might affect this relationship. Constraints of this study did not permit the testing of these variables, and the data cannot be used to predict upsurges of *L. laevigatum*. It would be useful for future studies to test environmental variables and determine whether population upsurges can be predicted using environmental factors.

As natural enemies are also important in regulating the population of *L. laevigatum*, it would be useful to look at monitoring of these as well as the pest itself. For an accurate estimate of the population variability, the study needs to be carried out for a longer period of time (approximately 10 years), and all factors which affect the presence of the wattle mirid need to be taken into account.

5.7 CONCLUSIONS

The establishment of a sound economic threshold would promote the development of integrated pest management, which would lead to reduced costs of production. There are still a number of important factors to be considered, but the results from this study have provided some preliminary results which can be used in future studies.

The forester should use two sampling methods to monitor *L. laevigatum*. Once eight adults are present on the 'Coke' bottle trap in one week, then sweep net samples of individual trees should be used to verify this information. Then, if an average of six adults are found per tree, control measures should be implemented. The traps need checking once a week during the summer months, and less often during the winter months. The forester needs to place a minimum of eight traps in a one hectare plantation. But these traps should give good coverage of the plantation, and so should be placed diagonally across the plantation.

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CHAPTER 6

GENERAL SUMMARY AND CONCLUSIONS

Wattle has become an important plantation tree as there is an increasing demand for its bark extracts for tanning, resins and adhesives. In 1993/94, *Lygidolon laevigatum* attacked 7078 ha of wattle, and it is estimated that it cost the wattle industry more than R124 500 to treat chemically (Govender 1994). The foresters do not notice the presence of the wattle mirid until the damage becomes visible. By this stage, however, it is often too late to employ effective control measures.

Monitoring of *L. laevigatum* is a complex subject that had not previously been addressed by the South African wattle industry. The aim of this study was to develop such a monitoring system for the wattle mirid, that would provide early indications of infestation and allow the forester to take action to prevent economic loss. Monitoring techniques to be used by foresters must be simple to operate and the data must be easy to interpret (Dent 1991). The traps must cost little to run, and be readily maintained (Dent 1991). This study has gone some way to providing the industry with a monitoring technique that is simple, reliable, cost-effective and practical.

Different types of trapping apparatus were tested: 1) instantaneous methods, such as: a) sweep net, b) D-vac machine and, c) beating tray; and 2) cumulative methods, such as: a) citrus trap, b) sticky board and, c) cylindrical plastic sticky trap. Results from these experiments indicated that sticky traps (cumulative trapping techniques) were the most practical and cost effective. Of the traps tested, the plastic cylindrical trap, constructed from a 2 litre 'Coke' bottle, was the most reliable and cost-effective trap (Chapter 2). Once the trap had been selected, other experiments concentrated on improving its usefulness.

An experiment was conducted testing different colours for the trap. Results indicated that *L. laevigatum* was a yellow-sensitive species. Further experiments then tested whether the wattle mirid responded to different hues of yellow. These results indicated that the wattle mirid was not sensitive to different hues. This experiment also looked at the costs of paints and 'Fasson' stickers. The paints (in particular, the 'Decade' paint "Golden yellow" SGE 08*B49) were cheaper than the stickers (Chapter 3).

Trap height was also tested. The results from this appear to indicate that the wattle mirid is found near the top of the canopy of the tree, and is significantly attracted to traps placed high up. A practical and reliable height for the trap is 2m above the ground (Chapter 4).

Population fluctuations suggest that careful weekly monitoring is required in the summer months when rainfall is high and the trees are flushing. In winter however, the monitoring regime need not be so regular, possibly every two weeks at most. Infestations appear to be random, with no distinct regular or clumped patterns (but this needs to be rigorously tested). It is therefore suggested that the traps are placed diagonally across the plantation. The number of traps required in a plantation appears optimally to be about eight, but this requires some further refinement, as these results are only from a one hectare plot (Chapter 5).

Ground-work for further studies on the economic threshold for the trap was carried out, and has provided some useful initial results. Tentative suggestions are that when eight adults are found on the trap in one week, and an average of six adults per tree are caught in a sweep net sample, control measures should be implemented. Further studies are required before the exact economic threshold can be ascertained (Chapter 5).

This reliable and cost-effective trap is a starting point for the development of an integrated pest management (IPM) programme for wattle plantations. Attaining the ideal of IPM is a stepwise process (Dent 1991) and results from this study have provided future researchers with the first step.

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