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HEMIPTERAN PEST DAMAGE ASSESSMENT AND MANAGEMENT IN WHITE CLOVER SEED CROPS

A Thesis
Submitted in Partial Fulfilment
of the Requirements for the Degree
of
Master of Agricultural Science
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By
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Hemipteran Pest Damage Assessment and Management in White Clover Seed Crops

By Neil Schroeder

Three field experiments were conducted in white clover seed crops at Lincoln, Canterbury, to determine:

(a) the incidence of pest and beneficial arthropods by suction sampling in three positions (edge, quarter and centre) into seven crops during the 1993-94 growing season (Survey Experiment).

(b) the seed yield losses incurred by different intensities of potato mirid (PM, *Calocoris norvegicus*) released in 0.81 m² field cages (Cage Experiment).

(c) the economic impact and effects on arthropod numbers from the application of two recommended insecticides (fluvalinate and dichlorvos), applied at the traditional timing for clover casebearer moth (*Coleophora spissicornis* and *C. frischella*) control (Spray Experiment).

Of the insect pests collected in the survey experiment, PM, blue-green lucerne aphid (BGLA, *Acythosiphon kondoi*), and brown shield bug (BSB, *Dictyotus caenosus*) were the most prevalent and most likely to cause economic injury to the developing flower heads and reductions in seed yields. PM nymphs and BGLA numbers peaked in mid-November (survey experiment), while BGLA numbers peaked in mid-January (spray experiment). BSB numbers occurred later in the season coinciding with the end of flowering and seed set in mid-January through to harvest (early February).

In the cage experiment the level of PM injury was highest on the stolon's second flower head and resulted in seed yield losses equivalent in value to $348/ ha at the PM (equivalent to 14-18 PM/ m²).
In the spray experiment fluvalinate controlled insect pest numbers for a longer period compared to dichlorvos. BGLA numbers in the fluvalinate-treated plots were significantly lower for up to 30 days after treatment. Lower numbers of the predatory Tasmanian lacewing (*Micromus tasmaniae*) also occurred in these plots. Seed yield gains from the application of either insecticide were financially profitable.
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Chapter 1

Growing White Clover Seed In New Zealand

1.1 The Value and Growing Practices Associated With White Clover

Canterbury is the main white clover seed producing area in New Zealand with 15,506 ha grown for certified seed in the 1993-94 season (Seed Certification Statistics 1993/94). The other areas of white clover seed production in that season were Northland (9 ha), Marlborough and Nelson (17 ha), and Otago and Southland (67 ha). New Zealand supplies over 80% of the world's market for white clover seed, earning about NZ$20 million in exports each year. Returns from overseas seed sales are small compared to earnings generated from New Zealand white clover based pastoral systems. As the legume base of the 9,600 km² of pasture land white clover contributes to $3 billion (1993) in overseas meat, $3 billion dairy product (1993), and $992.6 million (1993) wool exports (N.Z. Official Year Book, 1994). Estimates of fixed nitrogen by associated white clover root rhizobia is approximately 1.3 million tonnes N/year, equivalent to a $1.2 billion per year saving in nitrogen application (Widdup, 1994).

The average seed yields of white clover are dependent on the cultivar grown and crop management practices. Grasslands Huia is the main cultivar grown in Canterbury contributing 78% of the total certified white clover grown in the region (N.Z. Seed Certification Statistics 1993/94). Huia can be sown in autumn with ryegrass, or in spring with a pea or cereal (wheat and barley) crop and harvested after the other crop in the following season, or as a specialist crop sown in 15 or 30 cm spaced rows at 3-5 kg/ha depending on the time of sowing (McCartin, 1985; Clifford and Batey, 1983). Row spaced sowings are mandatory for the growing of new cultivars (Seed Certification 1993-94). Specialist seed growers with irrigation in the Canterbury region are achieving yields of up to 900 kg/ha, and averaging 600-700 kg/ha in favourable seasons when the crop is sown in the spaced rows (Clifford and Batey, 1983), compared to 250-400 kg/ha in undersown clover crops (McCartin, 1985).
1.2 Legume Seed Pests

Most of the previous work done on legume seed pests has centred on lucerne. Since 1975, however, the area in lucerne production for forage production has decreased dramatically from an estimated 220,000 ha (Dunbier et al., 1982) to the present 72,000 ha (Statistics New Zealand, 1992). This reduction has been blamed on several factors including stem nematode, *Ditylenchus dispaci* (Kühn), blue-green lucerne aphid, *Acyrthosiphon kondoi* Shinji, pea aphid, *A. pisum* (Harris), and sitona weevil, *Sitona discoideus* Gyllenhal (Dunbier et al., 1982). As a consequence the income from white clover seed crops well exceeds that of lucerne.

The insect seed pests and their beneficial arthropod predators associated with clover crops are presented in Table 1.1 with their respective reference sources.

Other arthropod pests associated with white clover crops and pastures are porina, *Wiseana* sp.; grass grub, *Costelytra zealandica* (White); springtail, *Bourletiella hortensis* (Fitch); lucerne flea, *Sminthurus viridis* (L.); and grey field slug, *Deroceras reticulatum* (Müller). The population dynamics and impact on white clover of these arthropods and mollusc are not included in this study.

Until quite recently, the primary insect pests associated with white clover seed crops were the clover casebearer moth, *Coleophora spissicornis* Haworth (banded casebearer) which was first recorded on Banks Peninsula in 1922, and *C. frischella* (L.) (whitetipped casebearer) first recorded in Hastings in 1944 (Pearson, 1982).

Clover casebearer larvae feed directly on the clover seed and uncontrolled populations have been reported to destroy more than 60% of the seed set in a crop (Pearson, 1982). The casebearers are the only white clover pest for which a control action threshold has been developed (Pearson, 1989).
Table 1.1 Pest and beneficial arthropods associated with white clover seed crops.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Classification</th>
<th>Scientific Name</th>
<th>Refs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian Crop-Mirid (ACM)*</td>
<td>Hemiptera: Mirididae</td>
<td><em>Sidinia kinbergii</em> (Stål)</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>Potato Mirid (PM)*</td>
<td>Hemiptera: Mirididae</td>
<td><em>Calocoris norvegicus</em> (Gmelin)</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>Bluegreen Lucerne Aphid (BGLA)*</td>
<td>Hemiptera: Aphididae</td>
<td><em>Acyrthosiphon kondoi</em> Shinji</td>
<td>3, 4, 9</td>
</tr>
<tr>
<td>Meadow Spittlebug</td>
<td>Hemiptera: Aphrophoridae</td>
<td><em>Philaenus spumarius</em> (L.)</td>
<td>5</td>
</tr>
<tr>
<td>Brown Shield Bug (BSB)*</td>
<td>Hemiptera: Pentatomidae</td>
<td><em>Dictyotus caenosus</em> (Westwood)</td>
<td>1, 2</td>
</tr>
<tr>
<td>Wheat Bug</td>
<td>Hemiptera: Lygaeidae</td>
<td><em>Nysius huttoni</em> White</td>
<td>1, 2</td>
</tr>
<tr>
<td>Banded Clover Casebearer</td>
<td>Lepidoptera: Coleophoridae</td>
<td><em>Coleophora gibba</em> Haworth</td>
<td>6</td>
</tr>
<tr>
<td>Whitetipped Clover Casebearer</td>
<td>Lepidoptera: Coleophoridae</td>
<td><em>Coleophora frischella</em> L.</td>
<td>6</td>
</tr>
</tbody>
</table>

**Beneficial Species**

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Classification</th>
<th>Scientific Name</th>
<th>Refs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eleven Spotted Ladybird (ESLB)*</td>
<td>Hemiptera: Coccinellida</td>
<td><em>Coccinella undecimpunctata</em> L.</td>
<td>7</td>
</tr>
<tr>
<td>Pacific Damself Bug (PDB)*</td>
<td>Hemiptera: Nabidae</td>
<td><em>Nabais kinbergii</em> (Reuter)</td>
<td>7, 9</td>
</tr>
<tr>
<td>Tasmanian Lacewing</td>
<td>Neuroptera: Hemerobiidae</td>
<td><em>Micromus tasmania</em> (Walker)</td>
<td>3, 10</td>
</tr>
<tr>
<td>Large Hover Fly</td>
<td>Diptera: Syrphidae</td>
<td><em>Melangyna novaedelavus</em> (Macquar)</td>
<td>11</td>
</tr>
<tr>
<td>Small Hover Fly</td>
<td></td>
<td><em>Melanostoma fasciatum</em> (Macquar)</td>
<td></td>
</tr>
<tr>
<td>Harvesman</td>
<td></td>
<td><em>Phalangium opilio</em> L.</td>
<td>7</td>
</tr>
<tr>
<td>Money Spiders</td>
<td>Arachnida: Linyphiidae</td>
<td><em>Leptophytes tenuis</em> (Blackwell)</td>
<td>8</td>
</tr>
</tbody>
</table>

* These abbreviations for the common names of the species marked will be used in the subsequent text.


Two small wasp parasitoids, *Bracon variegator* (Nees) and *Neochrysocharis* sp., were introduced from Europe in 1961-68 and 1961-1969, respectively Pearson (1989), to control casebearer populations. The parasitoids prefer the whitetipped casebearer and attack the cased fourth instar larvae (Early, 1984). Although the smaller *Neochrysocharis* sp. is more effective in controlling casebearers than *Bracon variegator*, the action of both parasitoids has markedly reduced casebearer populations to the extent that seed growers no longer apply insecticides for their control. The application of insecticides would have undoubtedly controlled other insect pests, however, since insecticide applications have been reduced there has been an increasing incidence in the number of damaged white clover flower heads thought to be caused by bug feeding.
Up until recently uneconomic white clover yields from second year crops were mainly associated with a population explosion of resident clover casebearer left from the previous season. Since the successful reduction in clover casebearers and the introduction of row spaced crops, there has been an increase in the area of white clover crops taken for two consecutive harvests.

Insecticides have been screened for both aphid (Trought, 1977) and mirid control in white clover and other legume seed crops by Wightman and Whitford (1982). Interim thresholds based on lucerne growth stages were developed by Wightman and MacFarlane (1981), but they have not been established for white clover seed crops. Of the insecticides screened by Wightman and Whitford (1982), pirimicarb applied for aphid control did not control mirids successfully and some of the recommended insecticides have since been removed from the market and new insecticides have been introduced.

1.3 Recent Developments in White Clover Seed Production

For the last twenty years Huia has been the main cultivar sown in New Zealand pastures and produced for export seed. In 1993 Huia was removed from the OECD recommended list¹, but because of the world shortage of white clover seed the price of Huia seed has not been yet affected. Huia is either autumn sown with ryegrass and taken for seed in the second season, or spring undersown with a cereal crop and taken for seed in the following season.

Major cultural and cultivar changes have occurred since the introduction of new requirements for growers wishing to change white clover cultivars (gazetted by the New Zealand Seed Certification Authority in 1986). To change a cultivar the field selected must have had no white clover grown in that field for the previous five seasons; the new crop must be sown in 30 cm spaced rows, as set out in Seed Certification 1993-94 regulations. The resultant quality assurance associated with these requirements combined with a high level of grower efficiency has been acknowledged by overseas clover seed companies to the extent that more than twenty overseas cultivars are now multiplied in New Zealand for re-export. As a consequence, instead

¹ A list of cultivars recommended for sowing in England, which also influences the rest of Europe.
of having the medium-leaved, main flowering-type Huia, whose flowering intensity is closely controlled by day length (peak-flowering about 19 December) (Thomas, 1981), we now have a full range from early (Grasslands Pitau, Prop) through to the late-flowering Grasslands Kopu, Aran, and Tillman. These new cultivars have a flowering period starting in the beginning of October through to mid-late February. Thus it is conceivable that the major pest spectrum may vary according to flowering type. Further compounding the issue is the fact that these cultivars also have a range of leaf sizes from small to large which corresponds respectively to both flower-bud and associated stolon densities being many to few. Thus pest density per se in relation to cultivar type may also affect the resultant pest injury level. Currently more than 70% of the present white clover crop area still remains in Huia managed traditionally with only 20% in row-spaced crops.

For this study the median-type, medium-leaved main-flowering, cultivar Huia has been chosen to gain preliminary information for the development of economic thresholds within white clover seed crops.

It has been observed that growers are unaware of the pest and beneficial arthropods occurring within their crops. Insecticides, if applied, are either inadequate for the control of some bug species, or are not timed according to action thresholds to gain the maximum economic benefits of application.

This study was initiated with the financial support from the Herbage Seed Sub-Section of Federated Farmers to fulfil the following objectives:

**Objective 1.** To evaluate the incidence of pest and beneficial arthropods occurring in local white clover seed crops during the 1993-94 growing season (Survey Experiment).

**Objective 2.** To determine the seed yield loss caused by differing intensities of potato mirids caged onto white clover plants grown within a crop (Cage Experiment).
Objective 3. To evaluate the efficacy of two recommended insecticides used for the control of Hemipteran insect pests, their impact on beneficial arthropods, and cost benefits of application in a white clover seed crop (Spray Experiment).
Chapter 2

Survey of Arthropods in White Clover Seed Crops

2.1 Introduction

Surveys are a form of monitoring strategy which are conducted to study the distribution of a pest, or they may involve a study of both the distribution and the abundance of a pest species (Dent, 1991). Monitoring a population of insects, whether beneficial or pestiferous, is a prerequisite for making a management decision and is a fundamental tool for insect pest management (Shelton and Trumble, 1990).

Surveys measuring both the distribution and abundance of insect species can be used to assess the relative level of pest infestation and may show up seasonal patterns of occurrence in different locations. These seasonal patterns may be related to differences in environmental conditions and may provide some understanding of factors influencing pest population dynamics. It is, therefore, desirable to base initial survey work on several seasons data to accommodate differences in seasonal patterns. The measurement of environmental factors may be used as future tools to predict impending pest outbreaks.

2.1.1 Sampling Techniques

When monitoring insect populations within a field consideration must be given to the purpose of sampling. An example may be to simply detect the presence of an insect within a crop (e.g., virus carrying aphids) in which case it would be advisable to sample those areas which previous experience and an understanding of the insect’s ecology has shown there to be a higher likelihood of infestation. Other elements for studying insect populations, besides purpose of sampling, are given by Ives and Moon (1987):

1. Definition of the target population and sample population.

2. Definition of sample unit, sample frame and methods of enumeration.
3. Preliminary sampling.

4. Precision, cost and number of sample units.

5. Schedule of sampling.

Insects can be counted directly, or their effects on crops assessed indirectly as injury or damage. Direct counts can be considered in two ways: those which can be based on a standard unit, such as an area of ground or weight of crop, or which can be converted to such a unit from the number of leaves, stems or plants per area or yield of crop. Alternatively pests can be counted in the environment, for example in a light trap, providing no more than a relative estimate of the population. In all cases, the method must be representative, or intended to give as true an estimate of the actual population as possible (Walker, 1987).

Because this study was designed to estimate the incidence of pest and beneficial arthropods occurring in white clover seed crops it was considered desirable to take direct counts based on a per unit area.

Overall estimations of insect populations can be achieved through random sampling techniques (Southwood, 1978). An alternative to random sampling is systematic sampling. This involves taking samples at fixed spatial intervals and is beneficial in determining patterns of infestation in the field which can then be incorporated into sampling methods (Shelton and Trumble, 1990).

Due to the prostrate growing nature of white clover, vulnerable growing tips are very close to ground level. The use of sweep nets and factors influencing their accuracy has been studied by Saugstad et al. (1967) within a lucerne crop. They found that the degree of variability of insect counts indicated that the precision of sweep nets may not be sufficient to make critical population comparisons, but they can be used to determine major population trends. However, sweep nets are not designed to sample close to the ground where the damage to white clover plants will occur.

An alternative sampling method which allows collection of insects at ground level is the suction sampler. Recently light-weight suction samplers adapted from home garden leaf-litter blower/suckers that are inexpensive have become available. Several papers (Stewart and Wright, 1995; McLeod et al., 1994) have been written on the efficiency of these samplers compared to the traditional D-Vac (Dietrick, 1961) suction sampler. The greater suction power of these new
suction samplers is reflected in the 10-60 fold greater weight of insects and debris collected. Linyphiid spiders which attach their webs to the soil or the base of plant stems were also collected in significantly higher numbers in the new suction sampler in comparison to the D-Vac when sampling grassland (Stewart and Wright, 1995). A further development of the light-weight suction sampler is the replacement of the collection bag or net with a plastic container for collecting the insects which can be stored for later identification. The 'Vortis insect suction sampler' manufactured by Burkard Manufacturing (U.K.) is an example of these light-weight suction samplers (Arnold, 1994).

2.1.2 Objective: To estimate the incidence of pest and beneficial arthropods occurring in local white clover seed crops during the 1993-94 growing season.

2.2 Materials and Method

2.2.1 Field Selection and History

Seven local Lincoln white clover seed crops were sampled once every two weeks to determine the incidence and density of both pest and beneficial insects (refer Table 1.1) occurring within these crops. Two white clover cultivars, Grasslands Huia (early flowering) and Grasslands Kopu (late flowering), were surveyed to determine whether there were any differences in insect densities between the two cultivars during the 1994-95 season. The five Huia crops were further divided into 'first' and 'second' harvest crops (Table 2.1). All Huia crops were undersown with a barley or ryegrass crop. The AgResearch Huia crop was sown with 45 cm row spacings during the autumn of 1993; the Kopu crops were sown with 30 cm row spacings. Descriptions of the size of the fields, harvest and sampling details are summarised in Table 2.1.
Table 2.1 Crop details and field descriptions used in the survey.

<table>
<thead>
<tr>
<th>Crop Location</th>
<th>Cultivar</th>
<th>Field Size (ha)</th>
<th>1st/2nd Harvest</th>
<th>Date Sampling Commenced</th>
<th>Final Sampling Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgResearch</td>
<td>Huia</td>
<td>1.0</td>
<td>1st</td>
<td>19/11/93</td>
<td>4/2/94</td>
</tr>
<tr>
<td>Bussell</td>
<td>Huia</td>
<td>8.0</td>
<td>1st</td>
<td>23/11/93</td>
<td>27/1/94</td>
</tr>
<tr>
<td>Griff</td>
<td>Huia</td>
<td>1.2</td>
<td>1st</td>
<td>16/12/93</td>
<td>4/2/94</td>
</tr>
<tr>
<td>Bussell</td>
<td>Huia</td>
<td>8.0</td>
<td>2nd</td>
<td>23/11/93</td>
<td>27/1/94</td>
</tr>
<tr>
<td>MacArney</td>
<td>Huia</td>
<td>4.3</td>
<td>2nd</td>
<td>9/11/93</td>
<td>27/1/94</td>
</tr>
<tr>
<td>Griff</td>
<td>Kopu</td>
<td>4.5</td>
<td>1st</td>
<td>23/11/93</td>
<td>4/2/94</td>
</tr>
<tr>
<td>College</td>
<td>Kopu</td>
<td>10.7</td>
<td>1st</td>
<td>23/11/93</td>
<td>27/1/94</td>
</tr>
</tbody>
</table>

2.2.2 Arthropod Identification and Recording

The arthropods collected were sorted into two broad groups; pest and beneficial. Eight species of known insect pests were identified in the samples (Table 1.1) and the numbers of each were recorded for each plot. Likewise, six species of known beneficial arthropods were identified in the samples (Table 1.1) and recorded for each plot. Adults of two species of hover fly, *Melangyna novaezelandiae* (Macquart) and *Melanostoma fasciatum* (Macquart), were collected in samples, along with their larval stages. Only the numbers of hover fly larvae are presented (Table 2.4) because adults are not predatory and, therefore, have no direct impact on pest numbers.

Field slugs, *Deroceras* spp., were collected when field conditions were moist (e.g., morning following a heavy dew). Slime produced by the slugs hampered suction sampling and later sample dissections by gumming specimens to the sampler and collection container surfaces. Samples were, therefore, taken later in the day to avoid these conditions.

Adults of the two species of clover casebearer, *C. spissicornis* (Haworth) and *C. frischella* (L.), were identified by differences between their antennae (Scott, 1984), however, the larvae of these species can not be distinguished morphologically and were recorded as one group.

Low numbers of wolf spiders, *Lycosa* sp., were collected infrequently, but numbers are not presented.
2.2.3 Sampling and Flower Counting Methods

Each crop was sampled at fortnightly intervals using a ‘Vortis’ suction sampler powered by a McCulloch 21.2 cm\(^3\) two stroke petrol engine (Plate 1) described by Arnold (1994). All samples were taken with the engine set at full throttle to keep a uniform suction for all samples. Sampling started on November 9 when potato mirids were first found in MacArtney’s Huia crop; the last field to be included in the survey was Griff’s Huia crop on December 16 (Table 2.1).

Plate 1. The author suction sampling a white clover crop in full bloom.

Three samples were taken at each of three positions in the crop (‘edge’, midway into the crop centre ‘quarter’, and the crop ‘centre’) to determine whether insects moved into the crop from vegetation around field margins. Preliminary fields counts at MacArtney’s indicated a high number of potato mirid (PM) in the edge of the crop only. The verges at which the ‘edge’ samples were taken were either roadsides, farm tracks, or a lucerne field in the case of MacArtney’s crop. Each sample was made up of ten 10-second suction samples covering an
area of 201 cm$^2$; this meant that 6030 cm$^2$ (0.603 m$^2$) was sampled for each field position. Suction sampling was done on representative clover plants only and bare ground and weed patches were avoided. The suction sampler collection containers were taken from the field and placed into a freezer at minus 10-20°C to kill and store insects for later identification.

Two flower counts were taken from each of the three sampling areas on each sampling date using a 500 x 500 mm metal quadrat.

Large numbers of strawberry root weevil, *Otiorhynchus ovatus* (L.), and later *Irenimus inaequulis* were found in Bussell’s ‘first’ and ‘second’ year crops, respectively. Counts were taken of these species, but are not represented in the following data because they were considered not to directly affect seed yields. Strawberry root weevil was noted by Downes (1922) feeding in white clover crops in Canada. Where there were high densities of strawberry root weevil and *Irenimus inaequulis* characteristic weevil feeding (notch-shaped) damage to leaves was apparent. However, no flower damage was found. Weevil larvae are known to feed on plant roots and their associated root nodules, as with Sitona weevil larvae, *Sitona discoideus* (Gyllenhal), attacking lucerne root nodules (Scott 1984).

**2.2.4 Weather Summary For Lincoln**

Below is a summary of the monthly (October to February) and long-term (1975-1991) rainfall, air temperature, and solar radiation means for the 1992-93 growing season (Table 2.2). These three variables were selected because they are most likely to have a direct bearing on plant growth and insect population dynamics.

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean Rainfall (mm)</th>
<th>Mean Air Temperature ($^\circ$C)</th>
<th>Mean Solar Radiation (Lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>7.7</td>
<td>54.9</td>
<td>12.4</td>
</tr>
<tr>
<td>November</td>
<td>75.6</td>
<td>55.7</td>
<td>10.9</td>
</tr>
<tr>
<td>December</td>
<td>99.8</td>
<td>61.3</td>
<td>13.1</td>
</tr>
<tr>
<td>January</td>
<td>52.4</td>
<td>50.3</td>
<td>16.8</td>
</tr>
<tr>
<td>February</td>
<td>37.8</td>
<td>51.3</td>
<td>16.4</td>
</tr>
</tbody>
</table>

*Table 2.2* Monthly summary of rainfall, air temperature, and solar radiation means for 1992-93 season and long-term means at Lincoln.
The mean rainfall during the 1992-93 season was, on average, higher than the long-term mean, especially during the main flowering period in November and December (Table 2.2). Mean air temperature and solar radiation were lower than the long-term average during the months of November and December. It would be expected, therefore, that white clover seed yields would be lower for the 1992-93 growing season.

2.3 Results

All data were analysed using the statistical package Genstat 5, release 3.1. Data for each insect species (Table 1.1) were analysed for significant differences between field positions over time with a generalised linear model using the Poisson error distribution. The insect counts were more likely to follow the Poisson distribution because the normal distribution is not a good approximation when counts are close to zero, as was the case with some samples collected. The results of the analysis for pest species are presented in Table 2.3, while those of beneficial species are presented in Table 2.4.

Because of the number of Huia crops and greater proportions of 1st year crops sampled, differences between cultivar and crop age could not be reliably evaluated, therefore all the data were pooled and then analysed for significant differences in arthropod densities between field positions over time.

All results have been converted from the original suction sample area of 0.603 m² per site and are presented on a per m² basis.

2.3.1 Insect pests

Aphids were recorded at the highest densities during the sampling period, averaging 40.55/m² over the three field positions, followed by adult potato mirids which were variable at the three sampling positions (Table 2.3).

When the values for each position were pooled for each insect and there was a significant (P<0.05) difference over time, then data for the 'edge', 'quarter' and 'centre' positions are
shown in graphs. When the overall values were significant (P<0.05) over time, but not significant (P>0.05) by position over time, then only the overall densities are shown in the graphs. Insects with densities less than 1/m² during the sample period are not graphed. The following insect pest graphs are presented in the same order as they appear in Table 2.3.

Table 2.3 Mean densities of insect pests at different field positions and their respective Poisson analysis of deviance results.

<table>
<thead>
<tr>
<th>Pest Species</th>
<th>Mean Densities/m² (±SEM)</th>
<th>Poisson Analysis of Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>'Edge'</td>
<td>'Quarter'</td>
</tr>
<tr>
<td>ACM (Adult)</td>
<td>0.26 ± 0.12</td>
<td>0.31 ± 0.13</td>
</tr>
<tr>
<td>ACM (Nymph)</td>
<td>0.52 ± 0.16</td>
<td>0.16 ± 0.09</td>
</tr>
<tr>
<td>PM (Nymph)</td>
<td>2.17 ± 0.33</td>
<td>0.54 ± 0.17</td>
</tr>
<tr>
<td>PM (Adult)</td>
<td>3.49 ± 0.43</td>
<td>3.73 ± 0.14</td>
</tr>
<tr>
<td>BGLA</td>
<td>36.17 ± 1.37</td>
<td>42.40 ± 1.48</td>
</tr>
<tr>
<td>Spittle bug (Adult)</td>
<td>0.82 ± 0.21</td>
<td>0.49 ± 0.16</td>
</tr>
<tr>
<td>Spittle bug (Nymph)</td>
<td>0.05 ± 0.05</td>
<td>0.08 ± 0.06</td>
</tr>
<tr>
<td>BSB (Adult)</td>
<td>0.26 ± 0.12</td>
<td>0.00</td>
</tr>
<tr>
<td>BSB (Nymph)</td>
<td>0.83 ± 0.21</td>
<td>0.16 ± 0.09</td>
</tr>
<tr>
<td>Wheat Bug (Adult)</td>
<td>1.30 ± 0.26</td>
<td>1.79 ± 0.30</td>
</tr>
<tr>
<td>Wheat Bug (Nymph)</td>
<td>0.78 ± 0.20</td>
<td>0.78 ± 0.20</td>
</tr>
<tr>
<td>Banded Clover</td>
<td>0.29 ± 0.12</td>
<td>0.67 ± 0.19</td>
</tr>
<tr>
<td>Casebearer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casebearer (Larvae)</td>
<td>0.99 ± 0.23</td>
<td>1.97 ± 0.32</td>
</tr>
<tr>
<td>Whitetipped Casebearer</td>
<td>0.16 ± 0.09</td>
<td>0.21 ± 0.10</td>
</tr>
</tbody>
</table>

ns = not significant (P>0.05).

**Australian Crop Mirid**

The densities of both adult and nymphaal Australian crop mirids (ACM) throughout the sampling period were very low in all fields averaging 0.28 and 0.31/m² for all three sampling positions, respectively (Table 2.3). There was a significant difference (P<0.001) in the densities of both adult and nymphaal ACM over time (Figure 2.1). Nymphaal ACM first occurred in the crops during the fifth sample period (0.24±0.14/m²) and increased in the following sample period to a
maximum 1.11 ± 0.32/ m². Adult ACM were first collected during the sixth sample period (0.46 ± 0.21/ m²) and increased to a density of 2.03 ± 0.61/ m² during the final sample period.

**Potato Mirid**

There was a significant difference (P<0.05) in potato mirid nymphal densities between sample positions over time (Table 2.3). Potato mirid nymphs were collected during the first four sample periods (Figure 2.2) with the highest density occurring in the 'edge' position over this period. The highest density recorded was 9.95 ± 2.87/ m² in the 'edge' followed by the 'quarter' position (8.71 ± 2.69/ m²) during the first sampling period. Densities of 19.9 and 17.4/ m² recorded at the 'edge' and 'quarter' positions of MacArtney's crop, respectively, were the main reason these high densities were recorded.
The densities of potato mirid adults were significantly higher (P<0.001) in the ‘edge’ and ‘quarter’ sample positions compared to the ‘centre’ position of the crop (Table 2.3). There was a significant difference (P<0.001) in adult densities between sample periods (Table 2.3 and Figure 2.3). Adult potato mirids were first collected during the second sample period (0.5 ± 0.26/ m²) and increased to an overall maximum of 4.61 ± 0.92/ m² at the fourth sample period.
Bluegreen Lucerne Aphid

There was a significant difference (P<0.001) in aphid density between sample positions over time (Table 2.3), although there was no clear trend between sample positions during individual sampling periods (Figure 2.4).

![Figure 2.4. Seasonal Densities (±SEM) of Aphid by Field Positions From Local White Clover Seed Crops](image)

The highest densities were collected during the first sample period in the ‘centre’ position (286.07 ± 15.40/ m²) followed by the ‘edge’ (263.68 ± 14.79/ m²) and ‘quarter’ (213.93 ± 13.32/ m²) positions. When data from all sample positions were pooled aphid densities declined to 8.92 ± 0.84/ m² during the fifth sample period, but increased to 49.75 ± 3.03/ m² during the final sample period.

Spittle Bug

There was a significant difference (P<0.05) in density of spittle bug adults between sample positions and sample periods (Table 2.3). However, densities were always lower than 1/ m².
**Brown Shield Bug**

Adult brown shield bugs were collected only once in the ‘edge’ position (0.39 ± 0.18/ m²), during the fifth sample period. A significant difference (P<0.01 and P<0.05) in adult shield bug density between sample position and sample period was detected (Table 2.3, Figure 2.5).

There was a significant difference (P<0.01) in densities of shield bug nymphs between sample positions (Table 2.3). Brown shield bug nymphs were only collected during the last three sample periods and reached a maximum of 1.84 ± 0.58/ m² during the final sample period (Figure 2.5). Densities for each of the positions were 2.21 ± 1.11 ('edge'), 1.11 ± 0.78 ('quarter'), and 2.11 ± 1.11/ m² ('centre').

![Figure 2.5](image)

**Wheat Bug**

There was a significant difference (P<0.001) in adult wheat bug densities between sample positions over time (Table 2.3). Adult wheat bugs were first collected in the centre of the crop during the second sample period and reached a maximum of 7.58 ± 1.34/ m² in the same position during the third sample period (Figure 2.6). There were no adult wheat bugs collected during the fourth sample period, but numbers had increased again during the following period.
There was no significant difference (P>0.05) in the densities of wheat bug nymphs between sample positions, however, there was a significant difference (P<0.01) in density between sample positions over time (Table 2.3). Wheat bug nymphs occurred later in the season compared to the adults and were first collected during the fifth sample period in all sample positions (Figure 2.7). The highest density (5.53 ± 1.75/ m²) was recorded from the ‘edge’ position during the final sample period.
Clover Casebearer Moth

The density estimates for both clover casebearer species were very low and highly variable (Table 2.3). Those casebearer larvae that were collected were in the mobile late third to fourth instar and immobile pupal stages. Therefore, it was likely that immature casebearer numbers were underestimated as the first three instars remain within the flower head to feed and are unlikely to be collected by suction sampling.

2.3.2 Beneficial Arthropods

Beneficial arthropod densities are presented as graphs according to the same criteria set down for insect pests.

Money spiders (Linyphiidae) were the most common beneficial arthropod collected during the sampling period and were found in similar densities at each of the three sampling positions (Table 2.4). Tasmanian lacewing adults were the next most common beneficial arthropod collected, but decreased in overall density from the edge of the crop into the centre.

Table 2.4 Mean densities of beneficial insects at different field positions and their respective Poisson analysis of deviance results.

<table>
<thead>
<tr>
<th>Beneficial Species</th>
<th>Mean Position Densities/ m² (±SEM)</th>
<th>Poisson Analysis of Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>‘Edge’</td>
<td>‘Quarter’</td>
</tr>
<tr>
<td>Eleven Spotted Ladybird (A)</td>
<td>1.17 ± 0.25</td>
<td>1.23 ± 0.25</td>
</tr>
<tr>
<td>Eleven Spotted Ladybird (L)</td>
<td>0.16 ± 0.09</td>
<td>0.79 ± 0.20</td>
</tr>
<tr>
<td>Pacific Damsel Bug (A)</td>
<td>0.78 ± 0.20</td>
<td>0.63 ± 0.18</td>
</tr>
<tr>
<td>Pacific Damsel Bug (N)</td>
<td>5.70 ± 0.54</td>
<td>2.23 ± 0.34</td>
</tr>
<tr>
<td>Tasmanian Lacewing (A)</td>
<td>15.15 ± 0.89</td>
<td>10.13 ± 0.72</td>
</tr>
<tr>
<td>Tasmanian Lacewing (L)</td>
<td>5.12 ± 0.33</td>
<td>5.70 ± 0.54</td>
</tr>
<tr>
<td>Hover Fly (L)</td>
<td>3.29 ± 0.41</td>
<td>2.44 ± 0.36</td>
</tr>
<tr>
<td>Harvestman</td>
<td>1.97 ± 0.32</td>
<td>1.19 ± 0.25</td>
</tr>
<tr>
<td>Money Spiders</td>
<td>30.80 ± 1.26</td>
<td>26.37 ± 1.17</td>
</tr>
</tbody>
</table>

A= Adult, L= Larval, and N= Nymphal stages
**Eleven Spotted Ladybird**

There was a significant difference ($P<0.001$) in adult ladybird density between sample periods (Table 2.4). Adult densities increased from $0.83 \pm 0.48/ \text{m}^2$ during the first sample period to a maximum of $2.43 \pm 0.44/ \text{m}^2$ during the third sample period, after which they declined steadily to $0.18 \pm 0.18/ \text{m}^2$ during the final sample period (Figure 2.8).

There were significantly ($P<0.05$) higher numbers of ladybird larvae collected from the ‘quarter’ and ‘centre’ sample positions compared to those collected at the ‘edge’ (Table 3). A similar trend was found with the distribution of aphids (Table 2.3). There was a significant difference ($P<0.001$) in larval ladybird density between sample periods (Table 2.4). The highest larval ladybird density was $3.48 \pm 0.69/ \text{m}^2$ during the second sample period.

![Figure 2.8 Seasonal Densities (+SEM) of Eleven Spotted Ladybird Adults and Larvae From Local White Clover Seed Crops](image)

**Pacific Damsel Bug**

There was a significant difference ($P<0.05$) in the density of damsel bug adults between sample periods (Table 2.4). Densities were low over the sampling season and reached a maximum of $1.11 \pm 0.32/ \text{m}^2$ during the final two sample periods (Figure 2.9).
There was a significant difference ($P<0.01$) in damsel bug nymphal densities between sample positions over time (Table 2.4). Damsel bug nymph densities were significantly ($P<0.001$) higher at the edges compared to the other two sample positions (Table 2.4, Figure 2.10). Nymphs were first collected during the second sample period, but decreased to $2.21 \pm 1.11$ nymphs/ m$^2$ in the ‘edge’ during the fourth sample period, but steadily increased to a maximum of $12.16 \pm 2.59/ m^2$ in the ‘edge’ position during the final sample period.

![Figure 2.9 Seasonal Densities (±SEM) of Pacific Damselfly Adult From Local White Clover Seed Crops](image)

![Figure 2.10 Seasonal Densities (±SEM) by Field Position of Pacific Damselfly Nymph From Local White Clover Seed Crops](image)
Tasmanian Lacewing

There was a significant difference (P<0.001) in lacewing adult densities between sample positions over time (Table 2.4). The adult lacewing density was significantly (P<0.001) higher in the crop edges compared to the other two sample positions (Table 2.4, Figure 2.11). The lowest numbers (3.40 ± 0.69/ m²) were collected during the second sample period, while the highest numbers (16.03 ± 1.13/ m²) were collected during the third sample period.

There was also a significant difference (P<0.001) in lacewing nymphal densities between sample positions over time (Table 2.4). The highest densities occurred during the second sample period with 32.71 ± 3.68 and 37.94 ± 3.97 nymphs/ m² being collected in the ‘quarter’ and ‘central’ field positions, respectively (Figure 2.12). Densities decreased during later sample periods reaching a minimum mean density of 0.74 ± 0.26/ m² (all positions pooled) at the sixth sample period.

Figure 2.11 Seasonal Densities (±SEM) by Field Position of Tasmanian Lacewing Adult From Local White Clover Seed Crops
Hoverfly

There was a significant difference (P<0.001) in hoverfly larvae densities over time (Table 2.4, Figure 2.13). Larval densities increased from 0.55 ± 0.21/ m², during the fifth sample period, to a maximum 18.24 ± 1.83/ m² in the final sample period.
**Harvestman**

There was a significant difference ($P<0.01$) in harvestman density between sample positions over time (Table 2.4). Harvestman were first collected in the field during the third sample period and increased in the next period to a maximum of $12.16 \pm 2.59/ \text{m}^2$ in the field centre (Figure 2.14).

![Figure 2.14 Seasonal Densities (+SEM) by Field Position of Harvestman From Local White Clover Seed Crops](image)

**Money Spiders**

Money spider densities were significantly ($P<0.001$) higher in the field edges compared to the other two field sampling positions (Table 2.4). There was also a significant difference ($P<0.001$) in spider densities between sample positions over time. Spider densities remained steady during the first five sample periods, but increased by over four times from $18.87 \pm 1.22$, (all positions pooled, fifth sample period) to $86.05 \pm 3.98/ \text{m}^2$ during the final sample period (Figure 2.15).
2.3.3 Flower Pattern

There were no significant differences (P>0.05) in the numbers of flowers at each field sampling position. The pooled means for each sample position over all sample periods were 23.63 ± 1.11 ('edge'), 22.65 ± 1.08 ('quarter'), and 22.85 ± 1.09/ m² ('centre'). There was a significant difference (P<0.001) in flower numbers between sample periods. Figure 2.16 represents the combined flower numbers of both clover cultivars monitored, however, as mentioned earlier the cultivars were selected for sampling on the basis of their different seasonal flowering patterns. The peak flowering for Huia crops was during the third sample period (December 5-18), while the peak flowering period for Kopu crops occurred during the fourth sample period (December 19-January 1).
2.4 Discussion

2.4.1 Sampling Efficiency

The densities of each of the target species (Table 1.1) were estimated by taking samples with a suction sampler during the survey experiment. The highest densities of the arthropods collected were BGLA and Linyphiids. The latter group was used as indicator species for determining sampler efficiency by Stewart and Wright (1995) and indicated that the sampler used in this study was collecting arthropods right down to the base of the crop. The efficiency of the sampler used in this study may have been impeded by the bulk of foliage associated with some crops, especially the Kopu crops. Vegetative growth in most of the crops was higher than expected and was likely to be due to the response of plants to the wetter and cooler spring conditions (Table 2.2).

Highly mobile arthropods may have escaped capture by the suction sampler as was observed with some adult PM flying away at the approach of the sampler. This would have resulted in an underestimated of the density of these species, although the extent of this underestimation was not determined.
The time of sampling also may have favoured the collection of some species over others. Leathwick and Winterbourn (1984) found that some predators, including harvestman, were higher in sweep net samples taken at night in a lucerne field and that lucerne aphids moved down the plant or onto the ground at night. ACM and PM, on the other hand, are diurnally active (Farrell and Stufkens, unpublished). Because of the prostrate growth of white clover compared to lucerne the suction sampler should have collected the arthropods whether active or not.

When statistical analysis was done to determine a reliable sample size for aphids it was found that three sets of 10 suctions per position gave an error term of over 20% of SEM. It was calculated that four sets of 10 suctions reduced variability to 12% of SEM for aphid density.

### 2.4.2 Sampling Positions

The decision to sample at regular distances into the crop was based on the preliminary sampling at MacArntney's 'second year' Huia crop where high numbers of PM were found in the crop 'edge' only. Over 60% of the arthropods collected showed a significant (P<0.05) difference in density between the three sampling positions. There was, however, no regularity in sampling distances into the crops sampled. While the 'edge' position was constant for each crop the distances to the 'quarter' sampling positions varied from 22 paces (AgResearch) to 132 paces (Bussell's 'second year' crop). This meant that arthropods moving into the crops from the verge increased in density earlier in the smaller fields compared to the large fields. In retrospect, better sampling method would have been to take samples at regular intervals into the crop which would then act as a standard for each crop (e.g., 'edge', 15m, 30m, half-way between 30m and the crop 'centre', and crop 'centre'). The last two distances being a factor of the field size.

### 2.4.3 Weather Variables

Weather variables would impact on both plant growth and arthropod numbers during the season. The effect of weather on the arthropods studied will be referred to in Section 2.4.4.

In 1993-94, Canterbury experienced the coldest and wettest growing season for the last 30 years. It was observed that many local farmers had given up on saving their clover crops for seed and were using the white clover to fatten lambs, or were harvesting them for silage and hay. The
main response of the plants to weather conditions is to grow vegetatively, however, it is moisture stress that enhances seed production (Clifford, 1985; Clifford 1986). Crops grown on the lighter soils provided the best yields for the season.

Vegetative and seed yields were not taken for the sampled crops in the survey experiment, which meant that the insect densities could not be related back to the impact on crop production. Future studies of this nature should include these variables (e.g., seed yields/ ha, 1000 seed weight, seed germination, and dry matter production), because these are the variables that the growers are most interested in, especially if a programme involves technology transfer for possible control recommendations.

2.4.4 Pest Insects and Crop Phenology

The incidence of insect pests occurring in the crops sampled will be discussed in relation to crop phenology to determine which species are likely to impact on seed production.

**Australian crop mirid (ACM)** were first recorded in New Zealand on passionvines by Myers (1922). In lucerne crops densities were highest during late January to mid-March (MacFarlane et al., 1981), while Farrell and Stufkens (unpublished) found that adults and nymphs reached high numbers in three peaks between December and April. The highest numbers collected in this study occurred during late January to early February (Figure 2.1). While ACM are probably the primary pest in lucerne seed crops, this species arrives late in the white clover season. This limits feeding damage to late flowers that may not mature seed in time for harvest. ACM were observed feeding from the green stalks of florets within the developed seed heads and this feeding could affect provisioning of the seed. Thousand seed weights and germination tests would indicate such damage. Pearson (1991) found that densities of one ACM per plant (released on December 2) caused a 50% reduction in the number of flower heads, an 18% reduction in the number of buds produced on each flower head, and a 26% reduction in the number of buds which produced florets. The number of seeds per head was also reduced. Densities during this survey were very low (<1/ m²) during the first five sample periods and could be attributed to the cooler season. Under normal conditions in Canterbury, Pearson (1991) reported that ACM populations in white clover crops are greatest after December, when
flowering is declining, but are prevalent earlier in drought conditions coinciding with peak flowering. Further sampling in subsequent seasons may help to clarify this point.

*Potato mirid* (*PM*) were first recorded by Cumber (1953) in pasture and fodder crops. In other studies nymphs and adults reached single peaks during November to January (Farrell and Stufkens, unpublished) and only adults were collected in mid-January by MacFarlane *et al.* (1981). A detailed study of the life cycle of *PM* in Waikato asparagus crops by Townsend and Watson (1982) found that first instar nymphs started emerging in mid-October with the first adults being recorded in mid to late November. *PM* had a higher damage impact on asparagus than the later occurring ACM. The same conclusions could be drawn for *PM* in this white clover study. The highest density of *PM* nymphs occurred at the first sampling (early to mid-November) and were significantly higher in the ‘edge’ and ‘quarter’ positions (Figure 2.2). The highly mobile adult numbers peaked during late December to early January throughout the crop (Figure 2.3).

*PM* numbers were highest when the clover crops were at their most vulnerable stage during flower development and through the flowering period (Figure 2.16). The impact on seed yields by *PM* is likely to be considerably greater than that by ACM and studies on the economic importance of *PM* are warranted.

Studies of *PM* in other crops may prove useful for developing approaches to their control in white clover crops. Outbreaks of epicarp lesion symptoms in pistachio fruit in California were due to feeding puncture wounds by several bugs, including *PM* (Uyemoto *et al.*, 1986; Michailides *et al.*, 1987). A day-degree model for the development of *PM* and timing management strategies was developed by Purcell and Welter (1990) who found that newly emerged nymphs required 142 degree-days to develop into fourth instar nymphs. Invasion occurred from uncontrolled weedy verges, similar to the verge invasion of *PM* in the white clover crops surveyed. Frequent disking and mowing of verge weeds and the application of insecticide before the adult dispersal into crops were the two main control approaches. Timing of insecticide application before the dispersal of *PM* in the ground cover significantly (*P*<0.05) reduced the level of epicarp lesion damage.

Moreby (1991a) found that *PM* were most abundant in the edges of wheat fields in England and carabid beetles in the conservation headlands appeared to have no predation effect on them.
If PM is shown to be of economic importance in white clover crops then this survey and the overseas literature indicates that insecticides should be applied around the crop verges after egg hatch and before adult development. This approach could result in reduced amounts of spray applied and overall spray costs.

**Bluegreen Lucerne Aphid (BGLA)** was first reported in New Zealand in 1975 by Cox and Dale (1977) five months after it arrived in Australia (Cameron and Walker, 1989). The abundance of aphids in white clover crops over time (Figure 2.4) was similar to populations of BGLA found in lucerne (Rohitha et al., 1985; Rohitha and Penman, 1986). The other possible aphid species were pea aphid, *Acyrthosiphon pisum* (Harris), and spotted alfalfa aphid, *Theriophis trifolii* forma *maculata* (Cameron and Walker, 1984), however, these two species usually occur during the warmer summer period (Rohitha et al., 1986) and were not recorded in this study.

Densities of BGLA in a lucerne crop peaked at 20,000/ m² in mid-November (Rohitha et al., 1985) and crashed to low levels following the peak. The collapse of BGLA was largely due to *Entomophora* spp., which are favoured by warm humid conditions (Nielson and Barnes, 1961). A wetter than average November and December (Table 2.2) could have caused similar conditions during this experiment, but temperatures were lower than average. Dispersal of alates would also contribute to losses in BGLA numbers. Rohitha et al. (1985) recorded a smaller peak occurring in mid-December with a corresponding increase in alate numbers and a third small peak in mid-March coinciding with an autumn flush of growth. These peaks were similar to those recorded by Kain et al. (1977) in Southern North Island lucerne crops and flight numbers of BGLA recorded by Rohitha and Penman (1986). Flight thresholds based on a day-degree model have been developed for BGLA in New Zealand lucerne crops (Rohitha and Penman, 1986), but are unlikely to be implemented for use in white clover seed crops.

Lindquist and Sorensen (1970) found that the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvios) a mirid pest in U.S. lucerne crops, was attracted to crops with high aphid densities. It was thought that the honey-dew produced by aphids acted as an attractant. When part of the crop was sprayed with a 10% sucrose solution 72% more bugs were found in the sprayed versus the unsprayed areas. Tarnished plant bug were also observed feeding on aphids. In the same way aphids occurring in large numbers at a clover crop edge may attract PM and ACM from verges into the crop.
Spittle Bug numbers were very low during the sampling period and although they can occur in high numbers, Pearson (1991) found that they did little damage to white clover seed yields.

Brown Shield Bug (BSB) nymphs and adults were observed on the green stalks of maturing florets within the flower head. As green stalks transport assimilates to developing seed, feeding by BSB may influence the seed weights (as determined by thousand seed weights) of damaged heads. It is likely that BSB feed by the 'lacerate and flush feed' system similar to mirids (Martin et al., 1988). It is also possible that the injection of salivary enzymes may effect seed germination.

Other studies on shield bugs have shown that these insects can have a significant impact on host plants. Three pentatomid stink bug species, Euschistus conspersus Uhler, Chlorochroa uhleri Stål, and Acrosternum hilare (Say), were found in large numbers in cotton crops grown next to lucerne fields (Toscano and Stern, 1976; Barbour et al., 1990). Stink bugs are mid to late season pests of cotton in parts of California. Stink bug injury to seed or fruit can be mechanical due to the penetration of the mouthparts and removal of plant fluids. The injury may also be physiological when salivary secretions of hystolytic agents (proteases and amylases) liquify and aid in the digestion of the solid and semi-solid portions of the cells (Nourteva and Laurema, 1961). Stink bug damage can also effect seed germination, reduce the oil content in soybeans, and lower the yield of the host crop (Yeargan, 1977; Simmons and Yeargan, 1983).

In New Zealand, MacFarlane et al. (1981) noted that although BSB numbers may be low compared to ACM in lucerne they may cause an equivalent amount of damage due to their larger size. Adult ACM weighed 2 mg, while BSB adults weighed 60 mg.

Wheat Bug densities in this study were considerably lower (Figure 2.6 and 2.7) than those found in lucerne and lotus crops by MacFarlane et al. (1981), but the ratio of nymphs to adults was similar during the equivalent periods. The nymphal instars occurred during the later half of the sampling period. Crops that were less dense or had bare ground patches were observed to have higher numbers of wheat bugs. Wheat bug is more prevalent during hot-dry seasons (Burnett, 1984). The impact of feeding damage of this pest on white clover seed production is not known, but the small numbers collected during the experiment suggest that it was of little economic importance in this season. Farrell and Stufkens (1993) found that this species overwinters as an adult in vegetative debris, under tree stump bark, and in gorse bushes. Annual
Weeds like shepherd's purse, *Capsella bursa-pastoris* (L.) Med.; sheep's sorell, *Rumex acetosella* L.; and wire weed, *Polygonum aviculare* L., are targeted as food sources by overwintered adults in spring, therefore weed control in verges of white clover seed crops may well be an important method of reducing their spread into the crop.

### 2.4.5 Relationship Between Insect Pests and Beneficial Arthropods

High densities of mirids may lead to cannibalism as found by Khattat and Stewart (1977) in cage experiments which contained unsuitable food for *L. lineolaris*. This is probably a density dependent interaction. There was no evidence of cannibalism among mirids or pentatomid bugs in the fields surveyed, however, cannibalism was observed in ladybird larvae which were in high numbers in the AgResearch crop on October 28, prior to the sampling period.

**Bluegreen lucerne aphid (BGLA)** were the predominant insect pest found in the survey experiment and probably represented the greatest pest biomass during the sampling period. Predation on BGLA has been reported in several papers. Leathwick and Winterbourn (1984) studied predation on BGLA and pea aphid in a Lincoln lucerne crop. Over 70% of the gut contents from the four most abundant predators found (Pacific damsel bug (PDB), eleven spotted ladybird (ESLB), lacewing, and harvestman) gave positive precipitin reactions to aphid-induced rabbit antiserum. The harvestman, *Phalangium opilio*, was considered to be a major aphid predator as high numbers were collected during night-time collections.

The effectiveness of some predators in regulating aphid populations may be limited, due to the lack of synchrony of their life histories with those of their prey (Cameron *et al.*, 1980). Nevertheless, ESLB has been noted to provide complete control of lucerne aphids occasionally (Cameron *et al.*, 1980) and was observed during the pre-sampling (late October) AgResearch crop. BGLA numbers decreased rapidly during the first and second sample periods (Figure 2.4) and remained at low densities for the remainder of the sampling period. During the initial decrease in BGLA numbers ESLB adult and larval (Figure 2.8), PDB adult and nymphal (Figure 2.9, 2.10), and larval lacewing (Figure 2.12) numbers increased rapidly. Ladybird and lacewing numbers decreased during the following samplings indicating a close synchrony to BGLA numbers over that period.
Significant numbers of harvestman (Figure 2.14) did not occur until half-way through the sampling period and few hoverfly larvae were found (Figure 2.13) until near the end of the sampling, reflecting a poor synchrony to the early BGLA population increase.

Money spiders are more likely to feed on fallen aphids landing in their webs, but the numbers of spiders (Figure 2.15) did not show any synchrony with BGLA numbers. Leathwick and Winterbourn (1984) found that lucerne aphid sweep net catches were 1.8 times higher during the day as opposed to night samples, suggesting that at night some aphids move down the stems or even off the plants making them vulnerable to ground dwelling predators like harvestman and money spiders.

Predation of aphids has been shown to be high by several species of arthropods inhabiting legume seed crops. Single predators placed in cages containing 40 third and fourth instar pea aphids were left for 48 hours and the percentage of aphids devoured determined (Leathwick and Winterbourn, 1984). PDB adults devoured 78%, PDB nymphs 75%, ESLB 70%, lacewing 73%, harvestman 84%, and wolf spider 25%, of the available aphids. Leathwick (1989) found that female lacewing adults ate approximately 11 first and second instar pea aphids per day at a controlled temperature of 15°C.

Other food sources besides BGLA were available to the predators during the survey experiment. Higher densities of ACM (Figure 2.1), BSB nymphs (Figure 2.5) and wheat bugs (Figures 2.6 and 2.7) were recorded later in the sampling period, which coincided with an increase in PDB (Figure 2.10), harvestman (Figure 2.14), money spiders (Figure 2.15), and hoverfly larvae (Figure 2.13). The latter is more likely to feed on aphids and any caterpillars present (Early, 1984).

Early (1984) and MacFarlane et al. (1981) reported that the PDB life cycle is well synchronised to ACM and likely to contribute significantly to its control, however, Siddique and Chapman (1987) found that PDB had a low feeding rate and could survive on one pea aphid every four days.
Chapter 3

The Effects of Different Caged Intensities of Potato Mirid on White Clover Seed Production

3.1 Introduction

Cages can be used to maintain pest infestations in isolation from the rest of the crop. In this way the level of attack in which the researcher is interested can be simulated irrespective of the size of the natural pest population (Dent, 1991). Cages can cover individual plants or large numbers of plants depending on plant size and spacing (Kouskolekas and Decker, 1968; Pearson, 1991; Simmons and Yeargan, 1990; Wratten, 1975). Large cages (e.g., 8 m², Wratten, 1975) that cover many plants have the advantage that the area contained within the cage can be considered as a plot and sampling carried out within it in the same way as other treatment plots and experiments. There should be sufficient cages to permit replication of both treatments (insect densities) and controls (cages having no infestation). The growth and yield of the crop inside and outside the control cages should be compared to determine the effect of the cage environment, and the treatment yields should be compared with the yields of plants in the control cages.

Yield loss assessments using artificial infestation techniques are not easy to carry out, however, if consideration is given to careful timing of inoculation (to simulate natural attack) this technique can provide the most effective method for controlled manipulation of conditions (Dent, 1991). Artificial infestation techniques can thus make the study of loss assessment more direct and refined.

Pearson (1991) studied the effect of meadow spittlebug and ACM on white clover clone production in small field cages (900 x 900 mm). While meadow spittlebug did not affect seed production, ACM at low densities reduced white clover seed production (refer ACM section 2.3.4). PM occurs earlier in the season, peaking in numbers during the flowering period and is, therefore, more likely to have a higher impact on seed production loss compared to ACM.
3.1.1 Objective: *To determine the seed yield loss caused by differing intensities of potato mirids caged onto white clover plants grown within a crop.*

3.2 Materials and Methods

3.2.1 Crop Management

The experiment was conducted in a 1.5 ha white clover (cv Grasslands Huia) seed crop grown on a Templeton silt loam soil type at AgResearch, Lincoln. The crop was precision sown in 45 cm row spacings at a rate of 3 kg/ha in late March 1993 to produce ‘breeders’ seed. Seed was sown with ‘Cropmaster 15’ (Ravensdown) fertiliser at a rate of 80 kg/ha and 5 kg/ha ‘Suscon Green’ (Nufarm) for grass grub (*Costelytra zealandica*) control. Twenty units of nitrogen (100 kg/ha ammonium sulphate) was applied on both September 7 and October 26.

Broadleaf weeds and grasses were controlled by spray applications of an experimental herbicide (active ingredient and rates not available, Dow Elanco) and ‘Galant’ (100 g/l haloxyfop, Ivon Watkins-Dow) at 400 g a.i. in 300 l water, plus crop oil per ha, respectively, on August 24. A desiccant herbicide (‘Buster’, 200 g/l glufosinate-ammonium, BASF N.Z. Ltd.) was applied at 1.2 kg a.i. with 60 ml surfactant (‘Citowett’, 100% alkylaryl polyglycol ether, BASF N.Z. Ltd.) in 300 l water per ha was inter-row sprayed to control weeds on September 3. Bentazone (‘Basagran’ 480 g/l bentazone, BASF N.Z. Ltd.) was applied at a rate of 1.44 kg a.i. with 50 ml a.i. ‘Citowett’ in 500 l water per ha on November 22 for chickweed (*Stellaria media*) control.

The crop was lightly topped with a mower to remove excess vegetative growth in mid-November, prior to flowering. Plots in blocks 3-5 were topped by hand shear to simulate the

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2 The seed breeder releases original ‘nucleus’ F1 seed every second or third year. This is to produce ‘breeders’ seed which is released to the clover grower to produce certified seed. The process ensures that the cultivar seed pool is kept true to type.
crop management practice within the cages. Plots in blocks 1 and 2 did not require topping because there was less vegetative growth.

The crop was irrigated with 25 mm water at the start of flowering on November 26. Two commercial honey bee hives, a 2-super hive within 20 m of the cage experiment and a 3-super hive within 200 m of the crop, were positioned on November 25.

### 3.2.2 Experimental design

Thirty 900 x 900 mm plots were obtained in the north-west corner of the crop covering an area of 40 x 6.3 m or 14 rows (Figure 3.1, Plate 2). The numbers of stolons per plot were counted in late November. Five potato mirid intensities (0, 0.2, 0.5, 1.0, and 2.0 mirids per five stolons, Table 1) were caged onto the plots on December 3 and 4. A sixth treatment (uncaged 900 x 900 mm plot) was used to determine whether there was any cage effect on clover growth and yield. The six treatments were replicated five times in a completely randomised block design (Figure 2.1).

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**Plate 2.** Cage plot lay-out. Note weather station position as in Figure 3.1.
Figure 3.1. Cage experiment design.
All plots were sprayed with 'Pyrethrum' (14 g/l pyrethrum and 56.5 g/l piperonyl butoxide a.i., Yates N.Z. Ltd.) at 3.17 g a.i. in 9 l water on December 1. A second application of pyrethroid insecticide ('Mavrik Aquaflow', 240 g/l fluvalinate a.i., Yates N.Z. Ltd.) at a rate of 36 g a.i./ha was made on January 4 1994, on the uncaged plots and caged plots with no mirids. Slug bait pellets (Mesurol, 20 g/kg methiocarb, Yates N.Z. Ltd.) were sprinkled at a rate of 3.3 kg a.i./ha over all plots on January 4 in an attempt to control slugs.

3.2.3 Cage Design

Cages consisted of four panels of nylon fly screen material (1 mm mesh size) stapled to a 50 mm square wooden frame that formed the four walls of the cage. The panels were fitted together by metal clamps. Nylon fly screen was stapled to the top of one panel and secured to the tops of the other three panels by Velcro strips to form the cage lid. The cages were assembled and placed on each of the caged treatments plots on November 30. They were kept in place by stamping soil around the base and with 2-300 mm long mild steel (5 mm dia) pins driven into the ground on each side.

3.2.4 Tagged Stolons

Before the cages were placed on each plot the centre was marked by a 900 mm long (30 x 30 mm) wooden stake hammered into the ground. From November 13 to 17 between 15 and 20 stolons at the first flower bud initiation stage were tagged in each treatment. A rubber ring was placed around the stolon and tied with a piece of string to the central stake for ease of recovery at harvest (Plate 4).

3.2.5 Potato Mirid Collection and Release

Potato mirids (third to fifth instar, Plate 3) required for the experiment were collected on December 3 and 4 from a local lucerne (cv Grasslands Otaio) crop. The mirids were collected with a sweep net, transferred into containers with 3-4 lucerne stalk tips and placed in a refrigerator in the laboratory for 5-10 minutes to reduce their mobility for ease of counting.
Plate 3. Fifth instar PM nymph feeding on white clover flower head. Note well developed wing pads.

The potato mirids were selected according to their mobility during the cool treatment recovery period. Each release consisted of a mixture of third to fifth instar mirids. The mirids were then taken to the field and carefully placed into their respective cages on the same day as their collection. The numbers/intensity of mirids released into each cage was based on a per 5 stolon basis and is summarised in the following table (Table 3.1).
Table 3.1 Number of potato mirids released into cages according to and total number of stolons per plot.

<table>
<thead>
<tr>
<th>Treatment mirids/stolons</th>
<th>Block 1 Stolons</th>
<th>Block 1 Mirids</th>
<th>Block 2 Stolons</th>
<th>Block 2 Mirids</th>
<th>Block 3 Stolons</th>
<th>Block 3 Mirids</th>
<th>Block 4 Stolons</th>
<th>Block 4 Mirids</th>
<th>Block 5 Stolons</th>
<th>Block 5 Mirids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncaged</td>
<td>308</td>
<td>0</td>
<td>320</td>
<td>0</td>
<td>392</td>
<td>0</td>
<td>308</td>
<td>0</td>
<td>330</td>
<td>0</td>
</tr>
<tr>
<td>Caged</td>
<td>270</td>
<td>0</td>
<td>378</td>
<td>0</td>
<td>330</td>
<td>0</td>
<td>360</td>
<td>0</td>
<td>332</td>
<td>0</td>
</tr>
<tr>
<td>0.2</td>
<td>374</td>
<td>15</td>
<td>350</td>
<td>14</td>
<td>380</td>
<td>15</td>
<td>350</td>
<td>14</td>
<td>296</td>
<td>12</td>
</tr>
<tr>
<td>0.5</td>
<td>280</td>
<td>28</td>
<td>330</td>
<td>33</td>
<td>332</td>
<td>33</td>
<td>360</td>
<td>36</td>
<td>386</td>
<td>39</td>
</tr>
<tr>
<td>1.0</td>
<td>280</td>
<td>56</td>
<td>210</td>
<td>42</td>
<td>420</td>
<td>84</td>
<td>346</td>
<td>69</td>
<td>420</td>
<td>84</td>
</tr>
<tr>
<td>2.0</td>
<td>346</td>
<td>138</td>
<td>300</td>
<td>120</td>
<td>374</td>
<td>150</td>
<td>330</td>
<td>132</td>
<td>352</td>
<td>141</td>
</tr>
</tbody>
</table>

On January 20, cages were inspected and only one adult potato mirid was found from 25 cages, therefore cage lids were removed to allow more sunlight penetration. Flower heads contributing to the seed yield were well developed at that time and, therefore, were not prone to damage by invading mirids.

3.2.6 Pollination and Flower Counts

Pollination within cages was achieved by the addition of one or two *Bombus terrestris* workers. Feral *B. terrestris* were collected using a sweep net on flowering shrubs grown in a pesticide-free area of the Lincoln University orchard and from laboratory-reared nests purchased by AgResearch for pollination of white clover grown in isolation screen cages. The first bees were placed in all cages on December 9 and restocked on December 12, and 28, and January 3, 4, and 10 with freshly collected bees.

Uncaged treatments were pollinated by bees from two bumble bee nests (one each of *B. terrestris* and *B. hortorum*, Figure 3.1) situated in the experimental area and honey bees from the two hives placed in the field on November 25.

Flower head counts were made from each plot on December 7 and 24 1993, January 4, and February 4, 1994 to determine the flowering pattern and to estimate the number of flowers within each treatment. The number of flower heads which had finished flowering in each plot were recorded on December 7 prior to the release of mirids. The stages of flower heads that were counted ranged from first floret opening to last floret opening.
3.2.7 Temperature and Weather Variables

A ‘Squirrel’ data logger (Grant Instruments, United Kingdom) was positioned between a pair of caged and uncaged plots in replicate 4 (Figure 3.1). Temperatures were recorded every two hours from probes placed at ground level. Recording started at 4 p.m. December 13 and concluded on January 4 at 10 a.m. The data were down-loaded onto a computer and the mean daily temperatures calculated. Previous temperatures and other weather variables, e.g., rainfall and sunlight hours were collected from the Lincoln, Crop and Food CRI weather station, within 1 km of the site (Table 2.2).

3.2.8 Harvest of Tagged Stolons and Plots

Stolons from each treatment were harvested from February 1 to 18 on a block by block basis. Initially as many as 20 stolons were collected from the first two replicates, but this number was reduced to 12 stolons per plot following a travelling mean (Wratten and Fry, 1980) analysis (9 samples minimum) of internodal lengths to assess the number of samples required. All stolons were then placed into individually labelled envelopes and stored in a freezer at -20°C to prevent deterioration. Internodal lengths of each stolon were measured at a later date. Flower heads from each harvested stolon were individually placed in envelopes and labelled according to their position on the stolon for later damage analysis. The counting of internodal lengths and flower head position started from the stolon base, (1), and continued to the growing tip, (4) for flower head number and (24) for internodal length (Figure 3.2).
Plate 4. Tagging of stolons made recovery later in the season easier, by tracing the string attached to the central stake back to the stolon.

Figure 3.2 Clover stolon showing internodal length and flower numbering.
All plots were sprayed with a desiccant herbicide (‘Reglone’, 200 g/l diquat, ICI N.Z. Ltd.) at 600 g a.i. on February 23. After 5-6 days all plots were harvested for total seed yield, by collecting seed which would have been conventionally harvested by machine (harvested) and by vacuuming the plots to collect seed which would usually be lost (unharvested) at harvest. ‘Harvested’ seed was collected by cutting the vegetation of each plot at ground level with hand shears and placing the vegetation in a large paper sack. ‘Unharvested’ seed was collected by vacuuming each plot with a McCulloch leaf suction machine and placing the debris in paper bags. All bags were then placed in a glasshouse for 2-3 days for further drying.

‘Harvested’ seed was threshed out using a ‘Kurtz Peltz’ machine while ‘unharvested’ debris was rubbed out on a corrugated rubber mat and sieved to collect the seed. Each sample was put through a ‘Seed Buro’ (USA) vertical air-draft separator set at two levels to differentiate between first and second seed qualities, consistent with commercial operations. Total seed weights, first and second quality, and thousand seed weights were recorded. Thousand seed weights were determined by the mean weights of three, one thousand seed samples counted by a ‘Seed Buro 801 Count-A-Pak’ (USA) machine set at a sensitivity of 0.2 and vibration speed of 55-60. ‘Harvested’ first yields per treatment were converted to a yield per hectare basis and dollar values estimated. These calculations are necessary in the development of economic thresholds.

3.2.8 Statistical Analysis

All statistical analyses were carried out using Minitab Version 8.2.

Block means for the ‘no-mirid’ treatments were analysed using a two-sample T-test to determine whether any differences occurred in yield components that may have been attributed to a cage effect.

Means (± SEM) for each treatment are presented in table form and are presented in three sections, stolon data, flower pattern data, and yield data. Analysis of variance was applied to all caged plot variables and significant results are identified in the text. These variables were
regressed against mirid intensity and those showing significant ($P < 0.05$) trends are presented graphically.

3.3 Results

The results are presented in two sections. The first section identifies any differences between the no-mirid treatments (caged versus uncaged) that may be due to a cage effect on plant growth and yields. The second section examines the impact of the five different mirid intensities (excluding the uncaged no-mirid treatment) on the tagged stolons, flower count, and harvest yield variables.

3.3(A) Caged vs Uncaged (No-Mirid) Plot Differences

3.3.1 Temperature Records

The mean ground temperature during the recording period was 1.1 °C higher in the uncaged plot ($17.1 \pm 0.7 \degree C$) compared to the caged plot ($16.0 \pm 0.7 \degree C$), however, there was no significant ($P > 0.05$) difference between means. The mean daily ground level temperatures were not recorded at the Crop and Food weather station, but monthly air temperature means are given in Table 2.2. The mean rainfall during the 1992-93 season was, on average, higher than the long-term mean, especially during the main flowering period in December (Figure 3.6). Mean air temperature and solar radiation were lower than the long-term average during the months of November and December. It would be expected, therefore, that white clover seed yields would be lower for the 1992-93 growing season.
### 3.3.2 Tagged Stolon Counts

The number of nodes per stolon for caged and uncaged plants was similar, but stolon lengths in the caged plots were, on average, 32.2 mm longer than those in uncaged plots (Table 3.2), however this difference was not significant (P > 0.05).

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Caged Mean ± SEM</th>
<th>Uncaged Mean ± SEM</th>
<th>T-value</th>
<th>d.f.</th>
<th>P (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tagged Stolon Data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nodes/Stolon</td>
<td>12.3 ± 0.6</td>
<td>12.4 ± 0.7</td>
<td>0.1</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Stolon Length (mm)</td>
<td>266.8 ± 29.0</td>
<td>234.6 ± 20.0</td>
<td>-0.9</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Total Flower Heads</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position on Stolon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head 1</td>
<td>11.0 ± 0.5</td>
<td>9.0 ± 1.0</td>
<td>-0.5</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Head 2</td>
<td>8.6 ± 1.2</td>
<td>8.6 ± 0.5</td>
<td>0.8</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Head 3</td>
<td>2.8 ± 0.6</td>
<td>3.2 ± 0.4</td>
<td>0.4</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Head 4</td>
<td>1.0 ± 0.0</td>
<td>2.0 ± 0.0</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Total</td>
<td>22.8 ± 2.1</td>
<td>21.2 ± 0.9</td>
<td>0.7</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Damaged Heads</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position on Stolon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head 1</td>
<td>0.4 ± 0.4</td>
<td>0.2 ± 0.2</td>
<td>-1.8</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Head 2</td>
<td>0.8 ± 0.4</td>
<td>1.2 ± 0.4</td>
<td>0.0</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Head 3</td>
<td>0.6 ± 0.3</td>
<td>0.4 ± 0.4</td>
<td>0.6</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Total</td>
<td>1.8 ± 0.7</td>
<td>1.4 ± 0.7</td>
<td>-2.6</td>
<td>8</td>
<td>ns</td>
</tr>
</tbody>
</table>

* Number of flower heads at position 4 were 2 in block 3 (caged) and 1 each in block 2 and 3 (uncaged).

The total number of heads and damaged heads was higher in the caged plots than in the uncaged plots by 1.6 and 0.4-fold, respectively.

Internodal lengths are not presented in Table 3.2, however, there was no significant (P > 0.05) difference between internodal lengths on stolons in the caged and uncaged plots.
3.3.3 Flower count data

The number of flowering heads were significantly higher (P< 0.05) in the caged plots compared to the uncaged plots when recording started on December 17 (Table 3.3). When flower counts were pooled from all recording dates, there was no significant difference (P>0.05) between the caged and uncaged plots (Table 3.3).

Table 3.3 White clover flower count means (± SEM) and T-test results for the caged vs uncaged no-mirid plots.

<table>
<thead>
<tr>
<th>Recording Date</th>
<th>Caged Mean ± SEM</th>
<th>Uncaged Mean ± SEM</th>
<th>2 Sample T-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 17</td>
<td>67.0 ± 3.2</td>
<td>50.2 ± 3.9</td>
<td>-3.3</td>
</tr>
<tr>
<td>December 24</td>
<td>70.8 ± 6.3</td>
<td>67.4 ± 3.1</td>
<td>-0.5</td>
</tr>
<tr>
<td>January 4</td>
<td>57.6 ± 3.4</td>
<td>57.0 ± 7.1</td>
<td>-0.1</td>
</tr>
<tr>
<td>February 1</td>
<td>9.8 ± 3.4</td>
<td>10.6 ± 1.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

3.3.4 Harvest yields

Uncaged plots gave higher yields than caged plots for all components analysed (Table 3.4), however, there were no significant differences between the mean estimates. Total first and second quality seed yields were 8.6 g and 1.3 g higher, respectively, in the uncaged plots compared to the caged plots.
Table 3.4 White clover plot yield means (± SEM) and T-test results for the caged and uncaged no-mirid plots

<table>
<thead>
<tr>
<th>Plot Yield Data (g)</th>
<th>Caged Mean ± SEM</th>
<th>Uncaged Mean ± SEM</th>
<th>2 Sample T-test T-value</th>
<th>d.f.</th>
<th>P (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Harvested' Firsts</td>
<td>37.4 ± 3.2</td>
<td>42.2 ± 3.6</td>
<td>1.0</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>'Unharvested' Firsts</td>
<td>13.4 ± 2.3</td>
<td>17.2 ± 3.3</td>
<td>0.9</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Total</td>
<td>50.8 ± 5.0</td>
<td>59.4 ± 4.2</td>
<td>1.3</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>'Harvested' Seconds</td>
<td>3.0 ± 0.6</td>
<td>4.1 ± 0.5</td>
<td>1.5</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>'Unharvested' Seconds</td>
<td>1.8 ± 0.5</td>
<td>1.9 ± 0.6</td>
<td>0.1</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Total</td>
<td>4.7 ± 0.6</td>
<td>6.0 ± 0.6</td>
<td>1.5</td>
<td>8</td>
<td>ns</td>
</tr>
</tbody>
</table>

3.3.5 Thousand seed weights

First quality thousand seed weight components were higher in the caged plots, but were lower for second quality thousand seed weight components compared to the uncaged plots (Table 3.5). The total first quality thousand seed weight was 0.01 g higher in the caged plots compared to the uncaged plots. The total second quality thousand seed weight was 0.014g lower in the caged plots compared to the uncaged plots (Table 3.5).

All other references to the uncaged plots will not be included in the following graphs or any subsequent statistical analysis.

Table 3.5 White clover thousand seed weight means (± SEM) and T-test results for the caged and uncaged no-mirid plots

<table>
<thead>
<tr>
<th>Thousand Seed Weights (g)</th>
<th>Caged Mean ± SEM</th>
<th>Uncaged Mean ± SEM</th>
<th>2 Sample T-test T-value</th>
<th>d.f.</th>
<th>P (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Harvested' Firsts</td>
<td>0.711 ± 0.007</td>
<td>0.692 ± 0.005</td>
<td>-2.2</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>'Unharvested' Firsts</td>
<td>0.687 ± 0.008</td>
<td>0.686 ± 0.010</td>
<td>-0.1</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Total Firsts</td>
<td>0.699 ± 0.004</td>
<td>0.689 ± 0.007</td>
<td>-1.2</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>'Harvested' Seconds</td>
<td>0.554 ± 0.007</td>
<td>0.562 ± 0.015</td>
<td>0.5</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>'Unharvested' Seconds</td>
<td>0.536 ± 0.009</td>
<td>0.555 ± 0.015</td>
<td>1.1</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Total Seconds</td>
<td>0.545 ± 0.007</td>
<td>0.559 ± 0.010</td>
<td>0.9</td>
<td>8</td>
<td>ns</td>
</tr>
</tbody>
</table>
3.3(B) Effects of Different Mirid Intensities

3.3.6 Tagged Stolons

The numbers of nodes per stolon were similar for each of the mirid intensities (Table 3.6). The longest stolons were harvested from the 0-mirid treatment and were on average 22.6 mm longer than the mean stolon length of the 1.0-mirid treatment (Table 3.6). There was a significant (P<0.01) block effect with total stolon length, which ranged from 211.0 ± 14.0 mm in block 5 up to 299.8 ± 19.0 mm in block 2.

Table 3.6 Tagged white clover stolon means (± SEM) for caged plots exposed to different mirid intensities.

<table>
<thead>
<tr>
<th>Tagged Stolon Variables</th>
<th>0.0 Mirids mean ± SEM</th>
<th>0.2 Mirids mean ± SEM</th>
<th>0.5 Mirids mean ± SEM</th>
<th>1.0 Mirids mean ± SEM</th>
<th>2.0 Mirids mean ± SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes/ Stolon</td>
<td>12.3 ± 0.5</td>
<td>12.8 ± 0.5</td>
<td>12.6 ± 0.5</td>
<td>12.7 ± 0.5</td>
<td>12.2 ± 0.5</td>
</tr>
<tr>
<td>Stolon Length (mm)</td>
<td>266.8 ± 17.9</td>
<td>263.1 ± 18.0</td>
<td>262.8 ± 19.3</td>
<td>244.2 ± 15.5</td>
<td>246.4 ± 17.8</td>
</tr>
<tr>
<td>Total Flower Heads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position on Stolon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head 1</td>
<td>11.0 ± 0.5</td>
<td>10.0 ± 0.6</td>
<td>8.8 ± 0.8</td>
<td>8.8 ± 0.6</td>
<td>9.6 ± 0.4</td>
</tr>
<tr>
<td>Head 2</td>
<td>8.6 ± 1.2</td>
<td>8.2 ± 0.6</td>
<td>6.8 ± 0.9</td>
<td>6.6 ± 0.5</td>
<td>6.6 ± 0.7</td>
</tr>
<tr>
<td>Head 3</td>
<td>2.8 ± 0.6</td>
<td>3.0 ± 0.9</td>
<td>2.0 ± 0.6</td>
<td>2.0 ± 0.6</td>
<td>2.0 ± 1.0</td>
</tr>
<tr>
<td>Head 4</td>
<td>1.0 ± 0.0</td>
<td>* ± *</td>
<td>1.0 ± *</td>
<td>1.0 ± 0.0</td>
<td>1.0 ± *</td>
</tr>
<tr>
<td>Total</td>
<td>22.8 ± 2.1</td>
<td>21.2 ± 1.5</td>
<td>17.6 ± 1.9</td>
<td>17.2 ± 0.6</td>
<td>17.8 ± 1.8</td>
</tr>
<tr>
<td>Damaged Heads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position on Stolon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head 1</td>
<td>0.4 ± 0.4</td>
<td>1.6 ± 0.4</td>
<td>1.2 ± 0.5</td>
<td>1.2 ± 0.6</td>
<td>1.2 ± 0.7</td>
</tr>
<tr>
<td>Head 2</td>
<td>0.8 ± 0.4</td>
<td>2.0 ± 0.6</td>
<td>1.4 ± 0.6</td>
<td>1.8 ± 0.7</td>
<td>2.6 ± 0.4</td>
</tr>
<tr>
<td>Head 3</td>
<td>0.6 ± 0.3</td>
<td>0.4 ± 0.3</td>
<td>0.0 ± 0.0</td>
<td>0.8 ± 0.3</td>
<td>0.5 ± 0.3</td>
</tr>
<tr>
<td>Head 4</td>
<td>0.0 ± 0.0</td>
<td>* ± *</td>
<td>0.0 ± *</td>
<td>0.0 ± 0.0</td>
<td>1.0 ± *</td>
</tr>
<tr>
<td>Total</td>
<td>1.8 ± 0.7</td>
<td>4.0 ± 1.1</td>
<td>2.6 ± 1.0</td>
<td>3.8 ± 1.0</td>
<td>5.3 ± 0.9</td>
</tr>
<tr>
<td>%Damaged</td>
<td>7.9</td>
<td>18.9</td>
<td>14.8</td>
<td>22.9</td>
<td>29.8</td>
</tr>
</tbody>
</table>

There was a significant (P< 0.05) negative quadratic relationship (y = 22.6 - 9.5x + 3.61x², r² = 86.4 %) between the total number of flower heads (y) and mirid intensity (x) (Figure 3.3). The lowest number of heads occurred in the 1-mirid intensity treatment, which was 5.6 heads lower than the no-mirid treatment. There was also a significant (P<0.05) block effect with flower head number, which ranged from 22.2 ± 2.0 heads in block 2 down to 16.4 ± 1.0 heads in block 4.
There was a significant (P<0.001) reduction in the total number of flower heads from head 1 to head 4 (Figure 3.4). When all mirid intensities were pooled the mean (±SEM) number of heads from 1 to 4 were 9.6 ± 0.3, 7.4 ± 0.4, 2.4 ± 0.3, 1.0 ± 0.0, respectively. The mean number of total flower heads (y) at each head position (x) is described by the negative linear relationship $y = 12.7 - 3.02x$, ($r^2 = 92.7\%$) (y-intercept P<0.05; S.D.=1.32; x-coefficient P<0.05; S.D.=0.48).

The highest flower head damage occurred on head 2 in the 2-mirid treatment, which was 1.8 heads greater than the no-mirid treatment (Figure 3.5). The pooled mean number (±SEM) of damaged heads from head 1 to head 4 were 1.1 ± 0.2 (11%), 1.7 ± 0.3 (23%), 0.5 ± 0.1 (21%), and 0.2 ± 0.2 (25%), respectively.
3.3.7 Flower counts

The total number of flower heads for each treatment over the four flower count dates are shown in Figure 3.6. The highest total number of flower heads occurred in the 0.2-mirid intensity treatment, which was 60.6 heads higher than the lowest total head number in the 2-mirid treatment. There was a highly significant (P<0.01) negative linear relationship ($y = 199.42 - 25.92x$ ($r^2=77\%$)).
3.3.8 Harvest yields

All of the following harvest weights are based on the caged area of 0.81 m².

Overall, seed weights in the no-mirid treatments were higher than those containing mirids, and there was a gradual decline with increasing mirid intensity (Table 3.7). ‘Harvested’ and total first quality yields were significant (P<0.01 and P<0.05, respectively) different between mirid treatments. There was a highly significant (P<0.001) block effect for ‘unharvested’ first quality yields, ranging from 6.6 ± 0.9g in block 5 to 20.7 ± 1.9 g in block 1. This contributed to a significant (P<0.05) block effect in total first quality harvest weights, which ranged from 34.3 ± 6.4 g in block 5 up to 51.5 ± 3.6 g in block 1.

There was a negative quadratic relationship (y = 36.10 - 23.75x + 8.84x², r²= 92%) between ‘harvested’ first quality seed weight (y) and mirid intensity (x) (Figure 3.7).
Table 3.7 Harvest yield means (± SEM) for caged plots exposed to different mirid intensities.

<table>
<thead>
<tr>
<th>Plot Yield Data (g)</th>
<th>0.0 Mirids mean ± SEM</th>
<th>0.2 Mirids mean ± SEM</th>
<th>0.5 Mirids mean ± SEM</th>
<th>1.0 Mirids mean ± SEM</th>
<th>2.0 Mirids mean ± SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Harvested’ Firsts</td>
<td>37.4 ± 3.2</td>
<td>30.4 ± 2.4</td>
<td>25.4 ± 1.6</td>
<td>22.4 ± 3.1</td>
<td>23.7 ± 3.2</td>
</tr>
<tr>
<td>‘Unharvested’ Firsts</td>
<td>13.4 ± 2.3</td>
<td>13.2 ± 3.4</td>
<td>11.7 ± 2.2</td>
<td>12.5 ± 3.4</td>
<td>9.8 ± 1.7</td>
</tr>
<tr>
<td>Total Firsts</td>
<td>50.9 ± 5.0</td>
<td>43.6 ± 4.1</td>
<td>37.1 ± 2.5</td>
<td>34.9 ± 5.8</td>
<td>33.5 ± 4.7</td>
</tr>
<tr>
<td>‘Harvested’ Seconds</td>
<td>3.0 ± 0.6</td>
<td>2.2 ± 0.3</td>
<td>2.4 ± 0.3</td>
<td>1.8 ± 0.1</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td>‘Unharvested’ 2nds</td>
<td>1.8 ± 0.5</td>
<td>1.2 ± 0.1</td>
<td>1.5 ± 0.3</td>
<td>1.1 ± 0.1</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>Total Seconds</td>
<td>4.7 ± 0.6</td>
<td>3.4 ± 0.3</td>
<td>3.9 ± 0.4</td>
<td>2.9 ± 0.2</td>
<td>2.0 ± 0.4</td>
</tr>
</tbody>
</table>

‘Unharvested’ first quality seed weights decreased as mirid intensity increased, except for the no-mirid intensity, which was slightly higher than expected. There was a negative linear relationship ($y = 13.35 - 1.70x, r^2 = 78.7\%$) between the ‘unharvested’ first quality seed weights ($y$) and mirid intensity ($x$) (Figure 3.7.).

There was a negative quadratic relationship ($y = 49.31 - 24.83x + 8.54x^2, r^2 = 89.4\%$) between the first quality total yield weights ($y$) and mirid intensity ($x$) (Figure 3.7).

Of the total first quality seed harvested from the cages the amount of ‘unharvested’ seed ranged from 26 (no-mirids) to 36% (1.0-mirids).

Figure 3.7 Mean (±SEM) First Quality Seed Yields From Caged Plots Exposed to Various Mirid Intensities

- "Harvested"
- "Unharvested"
- Total

Mirid Intensity/ 5 Stolons
'Harvested' and total second quality seed weights were significantly (P<0.01 and P<0.001, respectively) different between mirid intensity treatments (Figure 3.8). There was also a significant (P<0.01 and P<0.05, respectively) block difference in 'harvested' and total second quality seed weights, which ranged from 1.81 ± 0.42g and 3.04 ± 0.53g in block 2 to 3.21 ± 0.46g and 4.93 ± 0.84g, respectively.

Figure 3.8 Mean (±SEM) Second Quality Seed Yields From Plots Exposed to Various Mirid Intensities

'Harvested', 'unharvested', and total second quality yield weights all decreased linearly as mirid intensity (x) increased and are described by:-

- 'harvested' second quality yield = 2.679 - 0.76x  \( (r^2= 82\%; \text{ y-intercept } P<0.001, \text{ S.D.}=0.18; \text{ x-coefficient } P<0.05, \text{ S.D.}=0.17) \)

- 'unharvested' second quality yield = 1.57 - 0.42x  \( (r^2= 70.1\%; \text{ y-intercept } P<0.001, \text{ S.D.}=0.13; \text{ x-coefficient } P<0.05, \text{ S.D.}=0.13) \)

- Total second quality yield = 4.25 - 1.18x  \( (r^2= 77.9\%; \text{ y-intercept } P<0.001, \text{ S.D.}=0.31; \text{ x-coefficient } P<0.05, \text{ S.D.}=0.30) \)

Of the total second quality seed harvested from the cages the amount of 'unharvested' seed ranged from 36 (0.2-mirids) to 39% (2.0-mirids).
When the mean number of undamaged heads (Table 3.6) were regressed against the mean total yields for each treatment (Table 3.7), a highly significant (P<0.001) positive linear trend was found (Figure 3.9). The mean total yields (y) and mean undamaged heads (x) for the caged treatments is described by $y = 5.05 + 2.43x$ ($r^2 = 99.9\%$; y-intercept P<0.001, S.D.=0.05; x-coefficient P<0.01, S.D.=0.78).

3.3.9 Losses to the Grower

Estimates of seed yields from the treatment plots are given for the ‘harvested’ first quality seed in Table 3.8. Comparisons are made between the no-mirid and the four PM treatment plots, based on the season’s approximate seed yield returns at $4/kg.
Table 3.8  Plot yields for ‘harvested’ first quality seed converted to crop yields (kg/ha) and associated financial losses.

<table>
<thead>
<tr>
<th>Mirid Density/ m²**</th>
<th>0.0</th>
<th>0.2</th>
<th>0.5</th>
<th>1.0</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yields and Returns</strong></td>
<td>0.0</td>
<td>0.2</td>
<td>0.5</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>'Harvested' Firsts (g)</td>
<td>37.4</td>
<td>30.4</td>
<td>25.4</td>
<td>22.4</td>
<td>23.7</td>
</tr>
<tr>
<td>Kg/ha</td>
<td>462</td>
<td>375</td>
<td>314</td>
<td>277</td>
<td>293</td>
</tr>
<tr>
<td>Profit (at $4/kg)</td>
<td>1848</td>
<td>1500</td>
<td>1256</td>
<td>1108</td>
<td>1172</td>
</tr>
<tr>
<td>$ Lost</td>
<td>0</td>
<td>348</td>
<td>592</td>
<td>740</td>
<td>676</td>
</tr>
</tbody>
</table>

** Density is based on the number of PM released into the 0.81 m² cages and converted to a per m² basis.

Even at the lowest intensity the losses are high and warrant the use of insecticides for control. A possible economic threshold will be discussed in the general discussion and conclusions Chapter 5, but indications from this study would have the threshold set at a lower level than 0.2 PM per 5 stolons (14-18 PM/ m²).

3.3.10 Thousand seed weights

There was a significant difference (P<0.05) in ‘harvested’ first quality thousand seed weights between treatments. ‘Harvested’ first quality thousand seed weights ranged from 0.684 ± 0.002 g (0.2-mirids) to 0.711 ± 0.007 g (no-mirids Table 3.9).

There was a significant difference (P<0.05) in ‘unharvested’ second quality thousand seed weights between treatments. ‘Unharvested’ second quality thousand seed weights ranged from 0.528 ± 0.021 g (2.0-mirids) to 0.560 ± 0.013 g (0.5-mirids Table 3.9).
Table 3.9  White clover thousand seed weight means (± SEM) for caged plots exposed to different mirid intensities

<table>
<thead>
<tr>
<th>Thousand Seed Weights (g)</th>
<th>0.0 Mirids mean ± SEM</th>
<th>0.2 Mirids mean ± SEM</th>
<th>0.5 Mirids mean ± SEM</th>
<th>1.0 Mirids mean ± SEM</th>
<th>2.0 Mirids mean ± SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Harvested’ Firsts</td>
<td>0.711 ± 0.007</td>
<td>0.684 ± 0.002</td>
<td>0.693 ± 0.009</td>
<td>0.688 ± 0.007</td>
<td>0.696 ± 0.010</td>
</tr>
<tr>
<td>‘Unharvested’ Firsts</td>
<td>0.687 ± 0.008</td>
<td>0.682 ± 0.003</td>
<td>0.697 ± 0.007</td>
<td>0.686 ± 0.009</td>
<td>0.680 ± 0.011</td>
</tr>
<tr>
<td>Total Firsts</td>
<td>0.699 ± 0.004</td>
<td>0.683 ± 0.002</td>
<td>0.695 ± 0.007</td>
<td>0.687 ± 0.005</td>
<td>0.688 ± 0.010</td>
</tr>
<tr>
<td>‘harvested’ seconds</td>
<td>0.554 ± 0.007</td>
<td>0.543 ± 0.006</td>
<td>0.557 ± 0.007</td>
<td>0.547 ± 0.003</td>
<td>0.538 ± 0.008</td>
</tr>
<tr>
<td>‘Unharvested’ 2nds</td>
<td>0.536 ± 0.009</td>
<td>0.544 ± 0.013</td>
<td>0.560 ± 0.013</td>
<td>0.546 ± 0.011</td>
<td>0.528 ± 0.021</td>
</tr>
<tr>
<td>Total seconds</td>
<td>0.545 ± 0.007</td>
<td>0.544 ± 0.009</td>
<td>0.559 ± 0.009</td>
<td>0.547 ± 0.005</td>
<td>0.533 ± 0.013</td>
</tr>
</tbody>
</table>

3.4 Discussion

3.4.1 Experimental Design

Because there was a high variability in white clover plant growth within a crop it was necessary to use a randomised block design with five replicates to reduce statistical variability. Plant growth variability was evident in the period before flowering when the plots within blocks 3-5 were topped, while plots in blocks 1 and 2 were not. All other conditions within the cages were similar, so that any seed yield component differences between plots should have been attributed to differences in the applied PM infestations.

Shading from neighbouring cages was observed for a short period during the early morning and evening when the sun was low, but was not regarded as a yield reducing influence.

3.4.2 Cage Design

The cages remained in position throughout the whole experiment even though some strong winds were experienced.

The cage lids were secured by ‘sandwiching’ the fly screen between the hooked Velcro (stapled to the wooden cage frame) and the furry Velcro strip pushed through on top (i.e., Velcro-insect
screen-Velcro bond). Two cages in replicate four and five had their lids blown off during a strong north-westerly wind on November 10. Moisture from rain also buckled the hooked Velcro leaving gaps between the staples that insects could crawl under. Losses or gains of insects would have been minimal because the Velcro only buckled during cold wet weather when insects are less mobile and are taking refuge under plants. Future use of these and similar cages would be improved if the furry sided Velcro was glued and stapled to the wooden cage frame and the hooked sided Velcro was sewn onto the cage lid to make a Velco to Velco bond, which is stronger.

Only PM were found in the cages during the experiment, which showed good control from the applied insecticides and exclusion of invaders through the cage materials. Some slug damage was observed early in the experiment in the replicate five control cage, but subsequent damage did not occur following the application of mesurol bait on January 4.

3.4.3 Caged vs Uncaged (no-mirids)

All variables collected indicated that there was no significant difference (P>0.05) between the caged and uncaged no-mirid controls. Although seed yield components were slightly lower in the caged plots (Tables 3.4 and 3.5) there was no significant difference (P>0.05) found, which would indicate that the pollinators introduced into the cages were as efficient as those pollinators in the crop. Some bumble bees were still actively foraging inside the cages three weeks after initial release. Their durability and lower temperature flying threshold enabled them to forage even though the season was cooler than average. *B terrestris* under these conditions, proved to be excellent pollinators and support the observations made by Pearson (1991).

3.4.4 Harvesting Technique

The recovery of stolons was made easy by the tagging system adopted, however, some flowers were lost when they disintegrated during the untangling of stolons (refer Plate 4).

The harvesting methods used ensured that practically all seed was collected from the plots. Of the first quality seed collected from the caged plots 26-36% was lost by hand shear harvesting and was collected by the suction machine as 'unharvested'. This related to a loss of between 121
kg/ha (2.0 mirids) and 165 kg/ha (0-mirids) compared to normal field harvest losses of 460-720 kg/ha (12 to 39% of total) through the harvester offal trail and pick-up losses (Clifford and McCartin, 1985). The crop seed losses at pick-up for threshing and separation indicated that the operator and/or machinery were responsible for losses rather than crop management skills (Clifford and McCartin, 1985).

Although the caged plots appeared to have more vegetative bulk, the dry matter yields for each plot were not recorded. Tagged stolons in the caged no-mirid plots had an overall mean length 32.2 mm longer than those in the caged no-mirid plots but this difference was not significant (P>0.05). The number of nodes per stolon were similar in all treatment plots. The extra vegetative growth observed in caged plots was probably due to the position of plots in the crop. Although blocks 3, 4, and 5 were lightly topped because of the excessive vegetative growth, block 2 had significantly longer stolons (Table 3.6) (299.8 ± 19.0 mm) compared to block 5 (211.0 ± 14.0 mm). However, records of the dry matter production per plot may have indicated any reduction caused by PM intensity. The effect of PM on vegetative growth should be considered in consequent studies, because they are also found in large numbers in pastures and could be responsible for reducing production.

3.4.5 Differing Mirid Intensities

The standard unit of growth on a white clover plant is the stolon. Each node on a stolon has the ability to either produce a flower or more vegetative growth. The number of stolons per plant is a factor of growing conditions. The clover was grown in 45 cm row spacings to allow the maximum growth of stolons and, therefore, the maximum flowering potential for each plant. The number of stolons per plot were counted so that the same incidence of PM intensity would remain uniform over all plots with a similar treatment. These intensities could also be recalculated on a per unit area basis for the purpose of finding a threshold for sampling based on density. Pearson (1991) released ACM on hand planted clones on a per plant basis and concluded that the same experiment within a cropping situation should be pursued.

Infestations of PM significantly reduced all components of white clover seed yield. The number of flowers per plot decreased linearly as PM intensity increased (Figure 3.6), suggesting that flower buds were completely destroyed by feeding injury. Feeding injury has been shown to be
localised within a small area of plant tissue associated with the stylet lesion (Michailides et al., 1987; Uyemoto et al., 1986). Generally, the younger the buds when they are attacked, the greater the effect on seed yield. Buds which are at initiation and early development stage when attacked usually produce nothing (Pearson, 1991). The range of feeding injury is shown in Plate 5.

Pearson (1991) found that young stems which had been fed on by ACM shrivelled up and died, indicating that the salivary enzymes that were injected were translocated within the plant tissue. There were no significant (P>0.05) differences in stolon internodal length found between treatments in this experiment. This would suggest that the feeding behaviour and/or the toxicity of the salivary enzymes for ACM and PM are different. If this was the case it would be expected that the economic threshold for ACM would be set lower than that of PM.

Plate 5. The range of flower head injury (heavy on the left to light at right) caused by PM feeding. Feeding injury on early flower head buds caused total head loss.
An individual flower head takes approximately seven days from first floret opening to complete flowering (Clifford, pers. comm.). Florets at the base of the flower head are the first to develop, followed in succession up the head to the top florets (Figure 3.10). Assimilates moving into the flower head to the developing, fertile ovules are partitioned accordingly (Figure 3.10). This results in an average seed number of 3-4 per lower pod, compared to 2-3 in the later developing pods (Clifford, 1986).

PM were observed to favour flower heads which had started flowering. The circular petal pattern formed by the early florets may act as a visual attractant to PM, where the developing florets in the centre act as a readily available food source.

The flower head injury shown in Plate 5 shows that the lower florets went through to full development. Assimilates to these undamaged florets would have less partitioning pressure on them, compared to a fully undamaged flower head. It is expected that seed weights from these resultant pods would be higher than normal, but was not studied in this experiment. Partitioning within the flower head is studied by Clifford (1986), but requires study with respect to the specific injury inflicted by the different key hemipterans.

**Figure 3.10** A schematic diagram showing the partitioning of plant assimilates to the developing white clover seed head.
PM had the greatest impact on the second flower head (Figure 3.5), but if the releases occurred earlier with younger instars the impact could have been greater on both the first and second flower heads. Information on the nymphal stage present in the crop at the time of flowering is required to duplicate the same conditions within the cages.

The reduction of flowers that occurred as PM intensity increased translated in a reduced seed yield (Figure 3.9). Seed quality, measured by thousand seed weight, was also affected by increasing PM intensity. Germination testing is the main seed quality test used by seed merchants. Germination tests which also give indications of the hard seed content within the samples were not taken in this study, but they should be in future studies as they are factors which can influence the resultant price of the seedline.
Chapter 4

The Effects of Two Insecticides Recommended for use in White Clover Seed Crops

4.1 Introduction

Chemical insecticides have been the main method of insect control since the early 1950’s when organochlorine insecticides were first widely introduced. Subsequently, however, the wisdom of widespread use of chemical insecticides has been questioned. The long term future of chemical insecticides does not now lie in their wholesale use as the sole means to pest control, but rather in their judicial use in situations, dictated by the objectives of an Integrated Pest Management (IPM) programme. For the majority of pest species the use of chemical insecticides should only be a last resort, particularly for situations where it is known that prophylactic methods such as host plant resistance, natural enemies or cultural control can not constrain the pest to acceptable levels. In these situations chemical insecticides should ideally only be applied after an action threshold of pest numbers has been reached (Dent, 1991).

Few studies have focused on the evaluation of insecticides for control of mirid pests, or their impacts on beneficial species in legume seed crops. Insecticides suitable for the control of PM have been screened in the laboratory (Moreby, 1991). Of those screened dimethoate, demeton-S-methyl, fluoroxypr, tridemorph, and fenpropimorph controlled PM (Moreby, 1991). Another insecticide, pirimicarb, had no significant effect on PM (Wightman and Whitford, 1982). However, the most important insects in white clover crops are the pollinators, without which seed set would be minimal. When considering which insecticides to use for controlling insect pests in legume seed crops Wightman and Whitford (1982) proposed that the following criteria be considered:

1) The need to conserve populations of pollinators like honey bees and bumble bees that visit flowering legume crops which are afforded legal protection under the Apiaries Act 1969, Section 35. The safe use of pesticides toxic to bees is controlled under the Pesticides Regulations 1983.
2) The desirability of controlling pea aphid, the blue-green lucerne aphid, mirids and other pests.

3) The need to preserve predacious insects such as lacewings, ladybirds, and nabids.

4) The availability in New Zealand of selective insecticides which should be non-phytotoxic even if applied to plants suffering from moisture stress.

Of the four insecticides found to be effective against mirids (trichlorphon, bromophos, demeton-s-methyl, and endosulphan) by Wightman and Whitford (1982), only endosulphan is now commercially available. Endosulphan is recommended for the control of green vegetable bug, *Nezara viridula* (L.) and aphids, while dichlorvos is recommended for use in controlling clover casebearer (O’Connor, 1994). Fluvalinate, which is a more recently released insecticide, has been shown to be a safe chemical where honey bees are needed for pollination (Waller *et al.*, 1988). This insecticide is recommended for the control of clover casebearer moth and aphids in white clover seed crops (O’Connor, 1994).

Organophosphates like dichlorvos are highly toxic to mammals, but they are usually non-persistent and hence the residual effects are less of a threat to the environment than organochlorines (Edwards, 1987). Matthews and Clayphon (1973) placed dichlorvos in the moderately hazardous (to the operator) category. Synthetic pyrethroids like fluvalinate have extremely high contact activity and are particularly effective against lepidopterous larvae (King and Saunders, 1984). They have a low persistence and require appropriately timed application to be effective; they are also effective at very low doses (e.g., the recommended rate for fluvalinate is 36 g a.i./ha compared to 180 g a.i./ha for dichlorvos). Most pyrethroids, including fluvalinate, have a relatively low mammalian toxicity (Elliot *et al.*, 1978).

Having considered the pros and cons of using different insecticide formulations, the decision of whether or not to spray is governed mainly by application costs and whether the financial gains achieved through increased seed yields will cover these costs. An understanding of the seasonal abundance of insect pests, the impact of beneficial arthropods on pest populations, and the impact of different insecticides on both of these groups, including pollinators, are all factors that
require study. These variables, combined with the economics involved, form the basis for economic thresholds, which assist the grower in the decision-making process.

This experiment studies the impact of two insecticides, dichlorvos and fluvalinate, on pest and beneficial arthropods in a white clover seed crop and the financial gains/losses incurred with their application.

4.1.1 Objective: To evaluate the efficacy of two recommended insecticides used for the control of Hemipteran insect pests, their impact on beneficial arthropods, and cost benefits of application in a white clover seed crop.

4.2 Materials and Methods

4.2.1 Field Selection and Management

A spray experiment was conducted on a dry land 8 ha (Chertsey silt loam), first-harvest white clover (cv Grasslands Huia) seed crop located at Weedons (6 km west of Lincoln) on the property of Dennis Bussell. The field was selected on the basis of it’s size and shape, the uniformity and density of plants, and the presence of potato mirid nymphs when sampled with a sweep-net in mid-November 1993.

Grasslands Huia white clover was undersown at a rate of 3 kg/ ha with barley during the autumn (1992). A barley crop was harvested during January 1993 allowing the clover plants to establish in the autumn and spring. Herbicide (2,4-D butyl ester) was applied in November to reduce weeds.
4.2.2 Experimental Design

Field dimensions were estimated by pacing (ca. 1 m) the length (545 m) and width (188 m) to determine the maximum number of replicates that could be included in the experiment, based on 18 m wide treatment plots and 12 m strips around each replicate boarder (Figure 4.1).

The treatments were a water-only control with 50 ml ‘Superstick’ (100% non-ionic surfactants, Yates N.Z. Ltd.) in 200 l water per ha, a synthetic pyrethroid insecticide ‘Mavrik Aquaflow’ (240 g/l fluvalinate, Yates N.Z. Ltd.) at 36 g a.i. with 50 ml ‘Superstick’ in 200 l water per ha, and an organophosphate insecticide ‘Dichlorvos 100E’ (1000 g/l dichlorvos, Nufarm) at 180 g a.i. with 50 ml ‘Superstick’ in 200 l water per ha. Treatments were replicated eight times in a completely randomised block design (Figure 4.1).

The 12 m border around each block were sprayed with fluvalinate at 36 g a.i. with 50 ml ‘Superstick’ in 200 l water per ha.

Plate 6. Application of the insecticides on December 13 was done by a tractor-mounted spray unit during ideal, still and mild, conditions.
Figure 4.1. Spray experiment treatment field plan

- **C**: control
- **F**: fluvalinate
- **D**: dichlorvos

- Sampling positions in one plot
4.2.3 Spray Application

The treatment plots were marked by 900 mm long wooden stakes centrally placed at the ends of each plot. To identify the treatments [1 (control), 2 (fluvalinate), and 3 (dichlorvos)] numbered plastic container lids were stapled to the stakes.

The spray treatments were applied on two consecutive evenings (December 12 and 13). During the spraying of control plots (4.30-7:00 p.m. December 12) the wind increased and spraying was abandoned. Conditions on the following evening were still and warm (16-17 °C, Plate 6). Dichlorvos plots were sprayed first followed by the fluvalinate plots and borders (7:30-11:00 p.m.).

The plots were sprayed at a pressure of 200 kPa and a tractor speed of 6 kph using X.R Teejet 11003 VP nozzles. This required two passes of the sprayer (12 m and 6 m) to cover the 18 m width of the plots.

4.2.4 Insect Sampling Procedure

The insect samples were collected using a suction sampler. All plots were sampled in three positions, 47 m apart (Figure 4.1), making a total of 72 sample positions (3x24 plots) for each sampling date. The first samples were taken on December 11, 12 and 13. Replicates 7 and 8 were sampled with twenty 10-second suction samples at each position, but this number of samples was found to be too time consuming. All later sampling consisted of ten 10-second suction samples per sampling position. The 10-second suction sampling periods were selected on the basis of the number of 2nd and 3rd instar potato mirids collected over a range of suction periods (5 to 15 seconds) in a local clover crop; no improvement in the number of potato mirids caught after 10 seconds occurred.

The area covered by each sample was 201 cm², which equated to 2010 cm² for each of the sample positions and 6030 cm² (0.603 m²) for each plot.

Suction samples were collected on 3, 8, 15, 30, and 45 days after treatment (DAT) on December, 16, 21, and 28, January 13 and 28, respectively.
The suction sampler collection containers were taken from the field and placed into a freezer at minus 10-20°C to kill and store insects for later identification.

4.2.5 Pollination and Flower counts

Eight commercial honey bee hives were placed in the neighbouring second-year white clover seed crop within 300 m of the spray experimental crop (Figure 1) in early December. Feral bumble bees (e.g., Bombus terrestris) were also seen foraging within the crop during the experimental period.

Estimates of flower head densities were made at each of the 72 suction sampling areas using a 500 x 500 mm (0.25 m²) square metal quadrat. Flower counts commenced on December 13 when counts of both flowers which were flowering and those that had finished flowering were taken. This allowed an estimate of the total flowers per plot to be made at the end of the season. Subsequent flower head counts were of those flowering on December 21, January 5, 13, and 28. Flower counts in January were taken only from the control plots after analysis of the data from the previous two sampling days showed no difference in flower numbers between the three treatments.

4.2.6 Harvest Sampling

The crop was sprayed with a desiccant herbicide (Reglone, 200 g/l diquat, ICI N.Z. Ltd.) at 600 g a.i. in 350 l of water per ha on February 8. Three days later, 3 m x 45 cm (1.35 m²) strips were harvested at each of the three sampling positions per plot using a rotary lawn mower (Plate 7). The three harvested samples per plot were collectively placed into a large paper bag and oven dried at 80°C for three days. The dry weights of samples were recorded immediately after removal from the oven, however, weights were found to vary due to the presence of weed contaminants within the crop. Due to the mulching of samples by the mower it was impossible to obtain clean vegetative clover samples, so dry weight measurements were abandoned. Yarrow was the main weed contaminant in all treatments, especially in replicates three to six. The drying process rendered the clover seed non-viable for later seed quality germination tests. The dry plot samples were then threshed for clover seed using a Kurtz Peltz machine on
February 16. Some of the samples were still damp and were oven dried overnight and threshed on the following day.

Plate 7. Three days after the crop was sprayed with diquat desiccant, 3 m x 45 cm (1.35/ m²) strips were harvested at each of the three sampling positions per plot using a rotary lawn mower.

Each seed sample was put through a ‘Seedburo’ vertical air-draft separator set at two levels to separate first and second seed qualities (consistent with commercial operations). Total weights for first and second quality seed and 1000 seed weights were recorded. Thousand seed weights were determined by weighing four 1000 seed samples counted by a ‘Seedburo 801 Count-A-
Pale' apparatus set at a sensitivity of 0.2 and vibration speed of 55-60. Field madda, *Sherardia arvensis*, seeds were found as a contaminant in the seed samples thereby affecting the true 1000 clover seed weights. It was assumed that field madda was distributed throughout the whole crop, therefore, one of the four 1000 seed samples per plot was dissected and the number and weight of field madda seeds were recorded. The pooled mean for the number and weight of field madda seed for all seed samples were calculated for 1st (84.2 ± 11.2 field madda seeds weighing 0.080 ± 0.012 g) and 2nd (102.5 ± 11.6 field madda seeds weighing 0.044 ± 0.004 g) quality 1000 seed weights. The pooled contaminated 1st and 2nd quality 1000 seed weight means were 0.6387 ± 0.0095 g and 0.4843 ± 0.0151 g respectively. The corrected 1000 clover seed weights were 0.6105 ± 0.0051 g (95.6%) and 0.4910 ± 0.0137 g (101.4%) respectively. First and 2nd quality 1000 clover seed weight and plot harvest yield means were corrected using their respective proportions.

### 4.3 Results

All data were analysed using the statistical package Genstat 5, release 3.1. Data for each insect species (Table 1) were analysed for significant differences between treatments and interactions with a generalised linear model using the Poisson error distribution. The insect counts were more likely to follow the Poisson distribution and the normal distribution is not a good approximation when counts are close to zero, as was the case with some samples collected (Table 4.1 and 4.2). The results of the analysis for pest species are presented in Table 4.1, while those of beneficial species are presented in Table 4.2. The pooled means for all treatments are presented graphically for each species only when a significant difference (P<0.05) between sampling dates was determined. The spray treatment and treatment-time interactions which were significant (P<0.05) are also presented graphically to illustrate the difference between the three treatments over time. All the mean density estimates have been converted from the sampled area of 0.603 m² to a per m² basis after analysis.
4.3.1 Insect Pests

Table 4.1 Mean densities (back transformed) of pest insects in each treatment and results of Poisson analysis of deviance.

<table>
<thead>
<tr>
<th>Pest Species</th>
<th>Mean Densities/m² (±SEM)</th>
<th>Poisson Analysis of Deviance</th>
<th>Interactions Between Treatment and Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>control</td>
<td>fluvalinate</td>
<td>dichlorvos</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACM (Adult)</td>
<td>0.2 ± 0.1</td>
<td>0.2 ± 0.1</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>ACM (Nymph)</td>
<td>0.1 ± 0.5</td>
<td>0.2 ± 0.1</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>PM (Adult)</td>
<td>0.7 ± 0.2</td>
<td>0.4 ± 0.1</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>PM (Nymph)</td>
<td>0.4 ± 0.1</td>
<td>0.1 ± 0.1</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>Aphids</td>
<td>45 ± 1.3</td>
<td>43.0 ± 1.2</td>
<td>47.4 ± 1.3</td>
</tr>
<tr>
<td>Spittlebug (Adult)</td>
<td>4.6 ± 0.1</td>
<td>2.1 ± 0.3</td>
<td>3.6 ± 0.3</td>
</tr>
<tr>
<td>BSB (Adult)</td>
<td>0.2 ± 0.1</td>
<td>0.4 ± 0.1</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>BSB (Nymph)</td>
<td>2.1 ± 0.3</td>
<td>2.9 ± 0.3</td>
<td>3.3 ± 0.3</td>
</tr>
<tr>
<td>Wheat Bug (A)</td>
<td>0.7 ± 0.2</td>
<td>1.4 ± 0.2</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>Wheat Bug (N)</td>
<td>0.2 ± 0.1</td>
<td>0.0 ± 0.0</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>Banded Clover Casebearer</td>
<td>0.1 ± 0.1</td>
<td>0.2 ± 0.1</td>
<td>0.2 ± 0.1</td>
</tr>
<tr>
<td>Casebearer</td>
<td>0.5 ± 0.1</td>
<td>0.4 ± 0.1</td>
<td>0.3 ± 0.1</td>
</tr>
<tr>
<td>Casebearer (Larvae)</td>
<td>0.0 ± 0.0</td>
<td>0.1 ± 0.0</td>
<td>0.2 ± 0.1</td>
</tr>
<tr>
<td>Whitetipped Casebearer</td>
<td>0.0 ± 0.0</td>
<td>0.1 ± 0.0</td>
<td>0.2 ± 0.1</td>
</tr>
</tbody>
</table>

Trt = Treatment, C = control, I = Insecticide Treatments, F = fluvalinate, D = dichlorvos

Aphids were the most abundant pest occurring within the plots, while clover casebearer and Australian crop mirid were the most sparse (Table 4.1). The following graphs for individual pest species are presented in the same order as they appear in Table 4.1. Those pest species which have pooled densities below 1/m² are not presented in graphs.

**Australian Crop Mirid**

Low densities (<1 m²) of both adult and nymphs of ACM were found throughout the season in all plots (Table 4.1). Nymphal and adult ACM reached maximum densities of 0.4 ± 0.2 and 0.6 ± 0.2/ m² respectively during the sample period.
**Potato Mirid**

There was a significant (P<0.01) difference in potato mirid nymph density between the control and insecticide-treated plots (Table 4.1, Figure 4.2). The density of potato mirid nymphs decreased from sample day 0, (0.7 ± 0.2/ m$^2$) to 0/ m$^2$ 8 DAT, while for adults their density decreased rapidly from 1.21 ± 0.29/ m$^2$ prior to treatment application (Figure 4.1) to 0.4 ± 0.2/ m$^2$ 3 DAT. The density of adult potato mirid averaged 0.37/ m$^2$ up to 45 DAT.

![Figure 4.2. Potato Mirid Density Means (±SEM) for all Treatments Over Time](image)

There was a significant (P<0.01) difference in potato mirid nymph densities between the control and insecticide treatments over the sampling period (Table 4.1). However, densities were very low between 0 to 3 DAT when nymphs were collected from the treatment plots (Figure 4.3).
Bluegreen Lucerne Aphid

There was a highly significant (P<0.001) overall difference in aphid densities over time, a significant (P<0.05) difference in aphid densities by treatment interaction over time, and a significant (P<0.01) difference in aphid densities between the fluvalinate and dichlorvos treated plots over time (Table 4.1). The control and dichlorvos treatments followed a similar trend over the sampling period (Figure 4.4). By contrast, the fluvalinate treatment suppressed aphid numbers immediately after application up until 15 DAT when the mean density was 10.7 ± 1.6/ m$^2$ compared to 42.0 ± 3.2/ m$^2$ and 49.8 ± 3.5/ m$^2$ for the control and dichlorvos plots, respectively. Aphid densities increased rapidly in all treatments from 15 DAT and reached maximums of 174.5 ± 6.0, 176.1 ± 6.0, and 180.9 ± 6.1/ m$^2$ for the control, fluvalinate, and dichlorvos treatments, respectively, 30 DAT.

The aphid density decreased from 30 to 45 DAT at a rate of 11.2, 9.3, and 11.9 day/ m$^2$ in the control, fluvalinate, and dichlorvos treatments, respectively.
There was a significant (P<0.05) difference in adult spittlebug densities between the control and insecticide treatments (Table 4.1). Adult spittlebug densities were highest in the control plots at 6.5 ± 1.2/ m² before spray application, while the densities in the fluvalinate and dichlorvos plots were 5.9 ± 1.1 and 3.7 ± 0.9/ m², respectively (Figure 4.5). Three DAT, spittlebug densities in the control plots increased by 0.5/ m², while densities in the fluvalinate plots decreased from 4.9/ m² to 1.0 ± 0.8/ m². Adult spittlebug density decreased by 0.4/ m² to 3.3 ± 0.8/ m² over the same period in the dichlorvos-treated plots.

Control plot densities decreased at a steady rate of 0.2/ m²/day from 3 to 30 (1.8 ± 0.6/ m²) DAT and remained at a similar density until 45 DAT, while densities increased by 1.7/ m² in the fluvalinate plots from 3 to 8 DAT and decreased to 0.4 ± 0.3/ m² on 45 DAT. Adult spittlebug densities averaged 3.0/ m² from 0 to 45 DAT ranging from 3.7 ± 1.2/ m² (day 0) to 2.4 ± 0.7/ m² (day 30) in the dichlorvos plots.
Brown Shield Bug

Adult brown shield bug densities remained at an average 0.4/ m² during the period 0 to 45 DAT (Figure 4.6), while the density of nymphs increased from 0/ m² at 15 DAT to 4.7 ± 0.6/ m² and 11.5 ± 0.9/ m² at 30 and 40 DAT respectively. This represented an average density increase of approximately 0.4 brown shield bug nymphs/ m²/ day from 15 to 45 DAT.
**Wheat Bug**

Densities of wheat bug nymphs were below 0.5/ m² throughout the experimental period (Figure 4.7). Only four wheat bug nymphs were collected on each of 8 and 30 DAT. The density of adult wheat bugs increased from 0/ m² at 15 DAT to 3.5 ± 0.5/ m² at 30 DAT (Figure 4.7). This increase was possibly due to the greater numbers of adults m² (21) collected from replicate 8 of the fluvalinate treatment. The mean densities for each treatment at 30 DAT were 2.9/ m² (control), 7.0/ m² (fluvalinate), and 1/ m² (dichlorvos), which accounts for the significant (P<0.05) difference between the fluvalinate and dichlorvos treatments by sample day in Table 4.1. The pooled mean density for all treatments at 45 DAT decreased to 1.24/ m².

![Figure 4.7 Adult and Nymphal Wheat Bug Density Means (±SEM) for all Treatments Over Time](image)

**Clover Casebearers**

The density estimates for both clover casebearer species were very low and highly variable (Table 4.1). Those casebearer larvae that were collected were in the mobile late third to fourth instar and immobile pupal stages. Therefore, it was likely that immature casebearer numbers were under estimated as the first three instars remain within the flower head to feed and are unlikely to be collected by suction sample.
4.3.2 Beneficial Arthropods

The pooled means for all treatments are presented graphically for each species which gave a significant difference (P<0.05) between sampling dates. The spray treatment and treatment-time interactions which were significant (P<0.05) are also presented graphically to distinguish between the three treatments over time. All densities have been converted from the sampled area of 0.603 m² to a per m² basis.

Table 4.2 Mean numbers (back transformed) of beneficial insects in each treatment and results of Poisson analysis of deviance.

<table>
<thead>
<tr>
<th>Beneficial Species</th>
<th>Mean Densities/m² (±SEM)</th>
<th>Spray Treatments</th>
<th>Poisson Analysis of Deviance</th>
<th>Interactions Between Treatment and Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>control</td>
<td>fluvinate</td>
<td>dichlorvos</td>
<td>Trt C v I F v D Day Trt x Day [C v I] x Day [F v D] x Day</td>
</tr>
<tr>
<td>Eleven Spotted Ladybird (A)</td>
<td>3.1 ± 0.3</td>
<td>2.2 ± 0.3</td>
<td>2.6 ± 0.0</td>
<td>ns</td>
</tr>
<tr>
<td>Eleven Spotted Ladybird (L)</td>
<td>0.2 ± 0.1</td>
<td>0 ± 0</td>
<td>0.1 ± 0.1</td>
<td>ns</td>
</tr>
<tr>
<td>Pacific Damsel Bug (A)</td>
<td>0.4 ± 0.1</td>
<td>0.2 ± 0.0</td>
<td>0.2 ± 0.1</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Pacific Damsel Bug (N)</td>
<td>1.1 ± 0.2</td>
<td>0.4 ± 0.1</td>
<td>1.3 ± 0.2</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Tasmanian Lacewing (A)</td>
<td>11.1 ± 0.6</td>
<td>8.6 ± 0.6</td>
<td>12.1 ± 0.7</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Tasmanian Lacewing (L)</td>
<td>2.6 ± 0.3</td>
<td>1.3 ± 0.2</td>
<td>2.1 ± 0.3</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Hover Fly (L)</td>
<td>1.9 ± 0.3</td>
<td>2.3 ± 0.3</td>
<td>2.3 ± 0.3</td>
<td>ns</td>
</tr>
<tr>
<td>Harvestman</td>
<td>15 ± 0.2</td>
<td>1.0 ± 0.2</td>
<td>0.8 ± 0.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Money Spiders</td>
<td>102 ± 2</td>
<td>94 ± 2</td>
<td>110 ± 2</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Trt= Treatment, C= control, I= Insecticide Treatments, F= fluvinate, D= dichlorvos

Of all the nine beneficial species collected, money spiders were found in the highest densities followed by Tasmanian lacewing adults (Table 4.2). The following graphs of individual beneficial species are presented in the same order as they appear in Table 4.2. Those beneficial species which have pooled densities below 1/ m² are not presented in graphs.

Eleven Spotted Ladybird

There was a significant (P<0.001) difference between the number of ladybird adults in the control and insecticide treatments over time (Table 4.2). Adult ladybird densities in both the
fluvalinate and dichlorvos treatments decreased by 7.4 and 8.7/ m², respectively at 3 DAT to 1.6 ± 0.6/ m² (Figure 4.8). The adult ladybird density in dichlorvos plots increased slightly 8 DAT to 2.3 ± 0.7/ m², while in the fluvalinate plots density decreased by 0.2/ m² (1.4 ± 0.5/ m²). Fifteen to 45 DAT there was little difference in adult ladybird densities between the fluvalinate and dichlorvos plots, averaging 0.5/ m².

The density of adult ladybirds on control plots increased by 0.3/ m² from 0 to 3 DAT (7.0 ± 1.2 and 7.2 ± 1.3/ m², respectively) and decreased by 4.9/ m² from 3 to 8 DAT (2.3 ±0.7/ m²), to 0/ m² at 45 DAT.

For ladybird larvae a significant (P<0.05) difference between the fluvalinate and dichlorvos treatments occurred over time (Table 4.2), however, densities were very low with a high variance about the plotted means.

Pacific Damsel Bug

There was a significantly (P<0.05) higher density of Pacific damsel bug adults in the control plots compared to the two insecticide-treated plots, but there were no significant effects of time between treatments (Table 4.2). There was high variability about the means caused by the low numbers of adult bugs collected. The highest adult damsel bug density occurred prior to
treatment in the control plots at 0.8 ± 0.4/ m². There were no adult damsel bugs collected in any of the treatment plots at 3 DAT.

The density of damsel bug nymphs were 3 to 4 times higher than adults (Figure 4.9). A significantly (P<0.01) higher density (1.3 ± 0.2/ m²) of damsel bug nymphs occurred on dichlorvos plots compared to fluvalinate plots (0.3 ± 0.1/ m²) (Table 4.2). There was also a significant (P<0.001) difference in damsel bug nymphal densities between the control and the two insecticide treatments over the sampling days (Table 4.2). The highest density of damsel bug nymphs occurred prior to spray applications in the dichlorvos plots at 3.1 ± 0.8/ m². Following spray application of both fluvalinate and dichlorvos, densities of damsel bug nymphs decreased by 1.0 and 2.9/ m², respectively, to 0.2 ± 0.2/ m², while on the control plots the damsel bug nymphal density increased by 0.5/ m² from 0.4 ± 0.3 to 0.9 ± 0.5/ m² and increased by a further 2.0 nymphs / m² to 2.9 ± 0.9/ m² at 15 DAT. Overall, damsel bug nymphal densities were lowest in the fluvalinate plots.

**Figure 4.9 Pacific Damsel Bug Nymphal Density Means (±SEM) by Treatment Over Time**

![Graph showing Pacific Damsel Bug Nymphal Density Means](image)

**Tasmanian Lacewing**

Tasmanian lacewing adult densities were significantly (P<0.05) higher in the control (11.1 ± 0.6/m²) and dichlorvos (12.1 ± 0.7/ m²) plots compared to the fluvalinate (8.6 ± 0.6/ m²) plots (Table 4.2) and significantly (P<0.01) higher in the dichlorvos plots compared to the fluvalinate plots. There was no significant difference in density between treatments over the sampling days.
Adult lacewing density averaged 20.1/ m² in all plots prior to spray application (Figure 4.10). All treatment plot densities decreased following spray application. Fluvalinate and dichlorvos treatments caused decreases of 6.4 and 4.9/ m² to 6.4 ± 1.1 and 8.4 ± 1.3/ m² respectively, while there was a smaller decrease of 5.5/ m² to 13.4 ± 1.8/ m² in the control plots.

Three to 15 DAT adult lacewing densities continued to decrease in the fluvalinate plots at a rate of 0.2/ m²/ day compared to a 0.3/ m²/ day increase in the dichlorvos plots, and continued to increase to a maximum of 16.6 ± 1.9/ m² 30 DAT. All treatments had a similar density of 3.0/ m² by 45 DAT.

![Figure 4.10 Tasmanian Lacewing Adult Density Means (+SEM) by Treatment Over Time](image)

Lacewing larval densities were lower over the 45 day sampling period compared to adult densities. There was a significant (P<0.05) treatment by time interaction for fluvalinate and dichlorvos treatments (Table 4.2).

All treatment densities were below 1.1/ m² at 0 to 15 DAT after which they increased at different rates according to treatment (Figure 4.11). The highest rate of increase occurred from 15 to 30 DAT in the dichlorvos plots (0.2 ± 0.2 to 7.0 ± 1.2/ m²) at 0.5/ m²/ day compared to 0.4 and 0.0/ m²/ day in the control (0 to 5.2 ± 1.0/ m²) and fluvalinate (0.5 ± 0.3 to 1.0 ± 0.5/ m²) plots, respectively. The fluvalinate density was 6.0 and 4.2/ m² lower than the dichlorvos and control plots, respectively, at 30 DAT. The density of lacewing larvae in the control and fluvalinate
plots increased to $8.5 \pm 1.3$ and $5.2 \pm 1.0/\text{m}^2$, respectively from 30 to 45 DAT, while in the dichlorvos plots densities halved from $7.1 \pm 1.2$ to $3.5 \pm 0.9/\text{m}^2$ during the same period.

**Figure 4.11 Tasmanian Lacewing Larval Density Means (±SEM) by Treatment Over Time**

![Graph showing larval density means over time by treatment](image)

**Hoverfly Larvae and Harvestman**

There was a significant ($P<0.001$) difference in the hoverfly larvae and harvestman densities over time (Table 4.2). The harvestman density increased from $0/\text{m}^2$ before treatment to a maximum $1.7 \pm 0.3/\text{m}^2$ by 8 DAT and remained approximately at that density until 45 DAT (Figure 4.12).
The density of hoverfly larvae before spray application was $0.5 \pm 0.2\, \text{m}^2$ and decreased to $0.1 \pm 0.1\, \text{m}^2$, 3 DAT (Figure 4.12). Later sampling showed a slow increase in hoverfly larval density to $0.8 \pm 0.2\, \text{m}^2$ at 30 DAT, after which the density increased to $10.8 \pm 0.9\, \text{m}^2$ 45 DAT. This represented an average rate of increase of 0.7 hoverfly larvae/\text{m}^2/\text{day}.

**Money Spiders**

Money spider densities were significantly (P<0.05) higher in the dichlorvos ($109.0 \pm 1.9\, \text{m}^2$) plots compared to the fluvalinate ($93.8 \pm 1.8\, \text{m}^2$) plots (Table 4.2).
There was a decrease in spider density in all treatment plots following spray application at 3 DAT (Figure 4.13). The greatest decrease occurred in the fluvalinate (73.2 ± 3.9 to 42.2 ± 3.0/ m²) plots at 31.0/ m², compared to decreases of 25.6/ m² in the control and 9.5/ m² in the dichlorvos plots. From 8 DAT there was a steady increase in the number of spiders in all treatments at an average rate of 3.9/ m²/ day. The greatest difference between insecticide treatments occurred at 30 DAT when the mean density was 126.8 ± 5.1/ m² in the fluvalinate plots compared to 164.4 ± 5.8/ m² in the dichlorvos plots.

4.3.3 Flower Counts

There was no significant difference (P>0.05) in flower numbers between treatments on individual sampling days over the sampling period (Figure 4.14). The grand means for each treatment over the sampling period were 52.8 ± 1.3 (control), 52.9 ± 1.3 (fluvalinate), and 49.1 ± 1.2 flowers/ m² (dichlorvos). When flower numbers for all treatments were pooled there was a significant (P<0.001) difference in flower numbers between the four sampling days, which is reflected by the flowering pattern for the season (Figure 4.14). The highest number of flowers per m² occurred at 8 DAT (December 21) with 83.3 ± 3.2, 91.0 ± 3.4, and 76.3 ± 3.1 flowers/ m² in the control, fluvalinate, and dichlorvos plots, respectively. Flower numbers decreased steadily from 8 DAT to average 26.9 flowers/ m² by 31 DAT (January 13).
4.3.4 Seed Yields

The following seed yields are given on a per m$^2$ basis.

From the harvest strips (4.05 m$^2$) within the plots there was no significant difference (P>0.05) in yields of first quality seed between spray treatments (Table 4.3). The fluvalinate-treated plots had the highest mean first quality seed yield followed by the dichlorvos and control treatments (Table 4). This represented a difference of 2.69 g/m$^2$ in first quality seeds or the equivalent of 26.9 kg/ha between the fluvalinate and control treated plots (Figure 4.16).

The yields of second quality seed from the harvested plots were significantly (P<0.05) higher in the insecticide-treated plots, compared to the control plots (Table 4.3). The difference between the fluvalinate-treated and control plots was 1.1g/ m$^2$, which corresponds to 11kg/ ha second quality seed (Figure 4.16). The combined first and second quality seed yield difference between the fluvalinate-treated and control plots was 38.6kg/ ha compared to an overall yield difference of 10.9kg/ ha between the fluvalinate and dichlorvos-treated plots. There was no significant (P>0.05) difference in combined first and second quality seed yields between treatments.
Table 4.3 First and second quality white clover seed produced under different insecticide treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean (±SEM) Seed Weights (g/ m²)</th>
<th>Thousand Seed Weight Means (±SEM) (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Firsts</td>
<td>Seconds</td>
</tr>
<tr>
<td>control</td>
<td>12.9 ± 1.1</td>
<td>1.1 ± 0.2</td>
</tr>
<tr>
<td>fluvinate</td>
<td>15.6 ± 2.2</td>
<td>2.2 ± 0.5*</td>
</tr>
<tr>
<td>dichlorvos</td>
<td>14.8 ± 1.8</td>
<td>1.9 ± 0.2*</td>
</tr>
</tbody>
</table>

Significantly higher than the control treatment at (*) P<0.05 and (**) P<0.001.

![Figure 4.15 Harvested Seed Yield Means (±SEM) by Quality From The Various Spray Treatments](image)

4.3.5 Thousand Seed Weights

The thousand seed weights presented in Table 4.3 have been corrected for weed seed contamination in the samples.

There was no significant difference (P>0.05) in first quality thousand seed weight means between the three treatments (Table 4.3). The highest thousand seed weight mean was obtained from the dichlorvos-treated plots.
The second quality thousand seed weights were significantly (P<0.001) higher in the insecticide-treated plots compared to the control plots (Table 4.3). The highest thousand seed weight was obtained from the dichlorvos-treated plot.

4.4 Discussion

4.4.1 Insecticide Application

Dichlorvos is an organophosphate insecticide that has a contact and fumigant action (O'Connor, 1994). Because dichlorvos is highly volatile total plant coverage is not normally required especially for dense crops (O'Connor, 1994). Fluvalinate, a synthetic pyrethroid with less vapour pressure, requires an even and uniform coverage to achieve maximum contact of the target pests. Application in the evening is required for both insecticides to avoid contact with foraging bees. In this experiment the application of insecticides was done under optimal conditions on a mild (16-17 °C) still evening at the rates recommended by O'Connor (1994) for pest control in white clover seed crops. Because no thresholds have been developed for Hemipteran pests in white clover seed crops, the insecticides were applied in accordance with the times recommended for the control of clover casebearer moth (Pearson, 1982). The efficacy of the insecticide applications was studied in relation to target arthropod populations described in Table 1.1 over a 45 day period following spray application and related to resultant seed yields. The 45 day sampling period was likely to be the critical period over which the crop was vulnerable to insect damage.

All targeted species of arthropods (Table 1.1) were collected during the course of the experiment. The number of Lynophiids collected (Figure 4.14) were higher than those collected from the survey experiment (Figure 2.15), which indicated that the sampler was collecting all available arthropods present in the crop (Stewart and Wright, 1995).
4.4.2 Insecticide Impact on Insect Pests

Of the hemipteran pests sampled ACM numbers were very low before and after spray treatment application, as were the overall PM nymph numbers. PM nymph numbers were shown to be significantly (P<0.001) higher in the ‘edge’ and ‘quarter’ sampling positions in the survey experiment, however, the edge became the border in this experiment and was not sampled, as shown by the low numbers of PM nymphs collected (Figure 4.1). PM nymph numbers were, however, significantly (P<0.01) reduced in both the insecticide treated plots compared to the control plots (Figure 4.3), and adult PM numbers collectively declined at 3 DAT over all treatments to a third of those collected prior to treatment (Figure 4.2). The treatments appeared to be applied too late to control PM nymph numbers and the consequent spread of adults into the crop. Fluvalinate was found to be less effective in controlling mirids compared to other insecticides screened by Wipfli et al. (1989).

BGLA numbers were significantly (P<0.01) reduced by fluvalinate up to 15 DAT after which the numbers collected were similar to the other treatments (Figure 4.4). This indicates that fluvalinate residues had a prolonged suppressive effect on BGLA population build-up for an estimated 15 days. Similar studies by Gonzales et al. (1989) found that fluvalinate residues on raspberry plants were not detectable after 14 DAT at an application rate of 27.5 g a.i./ha and provided good control of the pest Tetranychus urticae Koch. Stein and Haverty (1990) reported a reduction of the aphid Mindarus victoria on white fur seedlings that lasted for 72 days after fluvalinate application. The apparent level of control will, however, also be related to the rate at which insects re-invade the treated crop.

Fluvalinate also effectively reduced adult spittle bug numbers (Figure 4.5), while BSB (Figure 4.6) and wheat bug (Figure 4.7) populations occurred later in the season when the insecticides had no residual effect. Both BSB and wheat bug incidence and densities were similar to those found in the survey experiment. Screening of insecticides and later application dates need to be studied for the control of BSB and wheat bug if they are shown to be of economic importance in future experimental work.
4.4.3 Timing of Insecticide Application

At the time of insecticide application the grower is not aware of how the season is going to progress and can only make management decisions based on prior experience, and from developed thresholds. The insecticides were applied according to recommended timing for clover casebearer control. The results of this study showed that timing of application was too late to effectively reduce PM nymph and resultant adult numbers, and too early to stop BGLA numbers from reaching a peak at 30 DAT in all treatments. The application was also too early to have any impact on BSB numbers. These three insect pests were shown to be of more importance (wider distribution and greater numbers) for white clover flower development in the survey experiment and in the cage experiment where high injury was recorded with low PM numbers. Investigation of the optimum timing of insecticide application for PM would be warranted.

4.4.4 Impact of Insecticides on Beneficial Insects

Promotional material from the distributors of fluvalinate in New Zealand (Yates N.Z. Ltd.) recommend the use of fluvalinate because it is 'bee safe' and beneficial insects like ladybirds and lacewings are not affected by application at the recommended rates. However, in this experiment both ladybirds and adult lacewing numbers reduced rapidly in fluvalinate and dichlorvos treated plots. Table 4.2 indicates that the overall means for predators was lowest in the fluvalinate treated plots. PDB nymph, adult lacewing and Lynphiid spider numbers were all significantly lower in the fluvalinate treated plots compared to the dichlorvos treated plots.

Other variables influencing predator populations like reproductive rate, rate of immigration from surrounding areas, the availability of a suitable food source, and spray residues could all be influenced by insecticide treatment. Statistical analysis on a per sample day basis showed that lacewing numbers were well synchronised to BGLA numbers, which suggested that low numbers recorded from the fluvalinate-treated plots were due to a lack of BGLA hosts. The residues of insecticides could also be repellent to predators. Whether any of the predators studied have a large impact on pest insect populations in white clover seed crops still requires assessment. Some predator-prey impact studies are discussed in Section 2.4.4. If they do not have a very important role then it may not be necessary to selectively apply insecticides like fluvalinate. The
impacts of the predacious species on the pest insects collected were discussed in Section 2.4.4, where it was suggested that the combined effect of several predators may have a large effect on pests (e.g., aphids).

4.4.5 Seed Yields

While the first quality seed yields were not significantly (P>0.05) different between treatments, there was a significantly higher (P<0.05) second quality seed yield from the insecticide treated plots compared to the control plots. Likewise, second quality thousand seed weights were significantly (P<0.01) higher than in the insecticide treated plots. The harvesting technique used ensured that very little seed was lost in comparison to the harvest losses of up to 39% described by Clifford and McCartin (1985).

While first quality seed yields were not significantly different, there is an obvious advantage when assessed in relation to contributing flower heads. Given mean treatment averages of 52.8, 52.9 and 49.1/ m², respectively for control, fluvalinate and dichlorvos then the seed heads required to gain one gram of seed are 4.1, 3.4 and 3.3, respectively, or a 22% advantage to the insecticide applied treatments. Of note is the opposite effect on seconds. The higher proportion of seconds in the total yield for fluvalinate (12.4%) and dichlorvos (11.4%) compared to control (7.9%) can be explained by the assimilates available for fertilised ovule provisioning (Clifford, 1986), discussed in Section 3.4.5.

The second quality seed yield increases gained by the application of insecticide would make the cost of application during this season uneconomical, however, the combined first and second yields do show an economic benefit from the application of insecticide. Fluvalinate costs $40.75 plus application costs of approximately $15.00/ ha to apply (total cost of $55.75/ ha), while dichlorvos costs $5.40 plus $15.00/ ha to apply (total cost of $20.40). Due to the poor growing season for white clover and the resultant low seed yields, seed prices were high at approximately $4/ kg. Calculations for overall returns to the grower based on combined first and second yields are given in Table 4.5.
Table 4.5  Net return from combined first and second quality seed yields (minus the cost of application).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Seed Yield (kg/ha)</th>
<th>Application ($/ha)</th>
<th>Costs</th>
<th>Net Return @ $4/kg (S/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>140</td>
<td>0</td>
<td>0</td>
<td>560.00</td>
</tr>
<tr>
<td>fluvalinate</td>
<td>178</td>
<td>55.75</td>
<td>0</td>
<td>656.25 (96.25**)</td>
</tr>
<tr>
<td>dichlorvos</td>
<td>167</td>
<td>20.40</td>
<td>0</td>
<td>647.60 (87.60**)</td>
</tr>
</tbody>
</table>

* Yield weights are based on means from Table 4.3.  ** Net gains from insecticide application.
Chapter 5

General Discussion

5.1 Integration of Results and Future Developments

Of the six major legume seed crop pests identified by Wightman and MacFarlane (1981), PM, BGLA, and possibly BSB populations seem to coincide with the critical flowering period for Grasslands Huia white clover and are probably the key insect pests in flowering white clover seed crops. Huia is a medium-leaved, main flowering-type white clover cultivar, which contributes to 78% of the total certified white clover grown in the Canterbury region. With the introduction of over twenty white clover cultivars grown in New Zealand, we now have a range of flowering patterns from early (Grasslands Pitau, Prop) through to the late-flowering (Grasslands Kopu, Aran, and Tillman) cultivars. The earlier flowering cultivars are predominantly grown on lighter-warmer soils, which also favour the development of the pests which occur earlier in the season (e.g., PM). While the later maturing cultivar yields may be significantly reduced by ACM, BSB and wheat bug which all increased in number later in the season. Therefore, it may be necessary to develop a range of economic thresholds to cover the range of flowering periods. These thresholds may be further refined by taking into account cultivar flower production. Lower thresholds for the large-leaved, low flower density cultivars (e.g., Kopu) compared to a higher threshold for the smaller leaved, high flower density cultivars (e.g., Pitau). Seasonal differences may also modify plant growth and development, which is dictated firstly by day-length and secondly by climatic conditions (Thomas, 1981). While insect development is mainly governed by day degrees (Dent, 1991). The inter-relationship between these plant and insect developmental variables requires further study to determine whether there are any seasonal variations.

The effects of insect feeding on stolon growth may modify the plant's vegetative and seed yielding capacity and this, in turn, may impact on the clover seed and pasture production use of white clover. Feeding by PM did not seem to affect stolon growth in the cage experiment, but Pearson (1991) found that ACM did reduce stem growth.
Low numbers of PM in the cage experiment caused high amounts of injury, which was similar to results found by Pearson (1991) for low numbers of caged ACM. Comparative cage experiments with both ACM and PM may help to determine injury differences between the two mirid species. Furthermore, identification of the salivary enzyme components for ACM, PM, and BSB in plant tissue could be used to identify where the insects are feeding on the plants and the resultant plant response to the injury. Of particular interest is the impact of pests on flower head assimilate partitioning.

BGLA numbers were variable between the surveyed crops. There may be a relationship associated with plant density that could be easily measured by vegetative dry weights and crop height in subsequent crop surveys. Most of the beneficial arthropods collected during sampling were known predators of BGLA. This was evident in the survey and fluvalinate-treated plots of the spray experiment where lacewing numbers were shown to be synchronised to those of BGLA. Of the predators found in the crop, all were likely to feed on the young ACM, BSB, and PM instars if caught. There is little evidence from this study and other literature of predation on PM ACM, or BSB. Harvestman may have an impact on these pests and their role within the crop deserves further investigation. It is likely, though, that BGLA are easier for harvestman and the other predators to capture and subdue, compared to the larger and highly mobile PM, ACM, and BSB, especially in the later instars.

The cage experiment allowed a preliminary study of a range of PM intensities within a field environment. The results showed that at low PM intensity/density the seed yield losses were high and warranted insecticide control. However, survey and spray experiment data indicated that high numbers of PM nymphs occurred earlier in the season before sampling commenced, especially around the crop verges. Control of these pests and consequent invasion of the highly mobile adults into the crop could be achieved by insecticide application around the field verges. This would reduce the cost and area of application.

BSB numbers were higher later in the season and were observed feeding on the developing seed heads at the seed-fill stage. Feeding during this period is likely to affect seed germination and thousand seed weight. Cage studies similar to the PM cage experiment would indicate any feeding injury caused by BSB on seed yield components.
Results from the spray experiment indicated that application of insecticides was economically beneficial, although there was no significant \( (P>0.05) \) difference between treatment yields. Twenty-two percent fewer flower heads were required to produce 1 gram of seed in the insecticide-treated plots, which also yielded higher second quality seed weights, compared to the control-treated plots. Assimilate provisioning was likely to be a main contributing factor to the latter difference. Several more seasons of crop monitoring to identify the key pests should be done over a range of areas where white clover is grown in the Canterbury region. Altitudinal and climatic differences may play an important role in the arthropod population dynamics. Once the key pests have been identified, screening of insecticides and other control techniques can be investigated. Reduction of host plants around the edge contamination of crop boarders could be achieved by herbicide application which would, in turn, decrease the incidence of pests like PM invading the crop from the boarders.

The timing of insecticide application was an important factor in the spray experiment and requires further investigation. One of the spray recommendations from this study would be the use of dichlorvos around the crop verge (i.e., one spray boom width of approximately 18 m) early in the season (October-November) for the control of invading pests, like PM nymphs, followed by a second application of either dichlorvos or fluvalinate, depending on insecticide screening results, for the control of BGLA or BSB should they reach a developed economic threshold level.

The use of different trap crops around the field verge, also warrants investigation. Field observations has shown that the two legumes sainfoin, *Onobrychis vicifolia* Scop., and sulla, *Hedysarum coronarium* are preferred host plants for hemipteran pests. Because these plant species are grow higher than white clover they may also act as a physical barrier and a favourable alternative food source for hemipteran pests and their predators. The concentration of pests and predators in a small area makes control by insecticide application less costly. If a selective insecticide is used the predators may be forced to move into the crop in search of food.
5.2 Implications To The Grower

Most growers are unaware of the arthropod fauna within their crops. BGLA is recognised as a problem due, mainly, to the high profile it received when it was first detected in high numbers in the late 1970's. They usually occur in large numbers and are, therefore, highly visible. Yet there have been no economic thresholds developed for BGLA in white clover seed crops, although Trought (1977) found that they were causing significant seed yield losses. Trought (1977), however, did not account for other insect pests present in the crop, like the mirids and clover casebearers and was likely to be erroneous in putting all seed yield losses down to BGLA damage. Because early instars of ACM and PM were wrongly identified as aphids by growers in the field, there is a need to equip and educate growers with suitable material and programmes for the identification of pests and predators. Secondly, the development of a sampling methodology and programme that enables growers to quickly and efficiently sample and process results for decision-making is needed. While the suction sampler used in this study was successful in collecting arthropods from throughout the crop structure, the initial cost of the instrument may be too high for growers. A simple and cheap suction sampler described by Stewart and Wright (1995) would be appropriate for most growers and warrants further efficiency studies. Sampling with a sweep net is another option available to growers. The use of sweep nets and factors influencing their accuracy has been studied by Saugstad et al. (1967) within a lucerne crop. They found that the degree of variability of insect counts indicated that the precision of sweep nets may not be sufficient to make critical population comparisons, but they can be used to determine major population trends. However, sweep nets are not designed to sample close to the ground where the damage to white clover plants will occur.

The development of a pest and beneficial identification booklet with monitoring advice and decision-making action thresholds is currently being developed in conjunction with the Herbage Seed Subsection of Federated Farmers.
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