PHENOLOGY AND MANAGEMENT OF HEMIPTERAN PESTS IN WHITE CLOVER (*TRIFOLIUM REPENS* L.) SEED CROPS, CANTERBURY (NEW ZEALAND)

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N.C. SCHROEDER

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ABSTRACT

New Zealand currently supplies approximately 60% of the world white clover (*Trifolium repens* L.) seed market, of which 99% is produced in the Canterbury growing region. However, this important cash crop may be infested by a range of insect pests which contribute to economic losses. The main aims of the research in this thesis were first, to identify the key economic pests in white clover seed crops by studying the interactions between plant and insect pest phenologies; second, to quantify the effect of selected pests on white clover seed production; third, to determine the most effective timing and placement of insecticide applications for controlling the pests; and fourth, to determine the synchrony of potential natural enemies with key insect pests.

Twenty four and fifteen white clover seed crops in the main Canterbury production areas were monitored for insect pests and arthropod predators in two successive growing seasons (1994-95 and 1995-96, respectively). Suction samples were taken at varying distances from the crop edge into the crop from mid-November until harvest to determine the abundance, spatial and temporal distribution of arthropods. The most abundant pests found in crops were potato mirid (*Calocoris norvegicus* [Gmelin]) and bluegreen lucerne aphid (*Acyrthosiphon kondoi* Shinji) which occurred in high numbers during the critical inflorescence formation and developmental stages (up to seed set). Potato mirid were found in higher densities around the crop margin (edge to 4 m into the crop) compared with bluegreen lucerne aphid that were more widely distributed throughout the crop.

A field cage experiment was conducted to determine the impact of different potato mirid densities (0, 10, 20, 40 and 80/cage) and high numbers (200/plant) of bluegreen lucerne aphid released at different plant growth stages (first and second inflorescence development, and full flowering) on inflorescence expression, seed production and yield. Loss of inflorescences and increased proportions of damaged inflorescences increased with increasing potato mirid densities and a significant linear relationship between increasing potato mirid density and declining seed yield was established. The highest level of inflorescence damage from bluegreen lucerne aphid feeding occurred at full flower and in a treatment where low infestation numbers (50/cage) were allowed to build up to 2100/cage. Significantly lower seed quality (thousand seed weight), but not overall seed yields were recorded from these field cages.

The timing and placement (crop edge to 6 m into the crop) of three insecticides (lambda-cyhalothrin, fluvalinate and pirimicarb) for the control of potato mirid and bluegreen lucerne aphid were evaluated in a field experiment. Lambda-cyhalothrin gave the most effective control of potato mirid, while pirimicarb was ineffective against potato mirid, but gave effective bluegreen lucerne aphid control. The earlier (late November) rather than traditional (early December) application of insecticides resulted in an extended period of control of potato mirid and bluegreen lucerne aphid during inflorescence development and produced higher seed yields compared with later application timings.

In a single white clover seed crop an intensive sampling experiment was conducted to study the spatial and temporal distribution of insect pests for the development of a crop sampling programme. An insecticide spray action threshold of 10 potato mirid nymphs in the crop margin (crop edge to 4 m into the crop) was established, while an action threshold (2 or 4 bluegreen lucerne aphid/inflorescence) for bluegreen lucerne aphid control was developed from other studies in white clover seed crops. Application of insecticides to control potato mirid and bluegreen lucerne aphid numbers exceeding thresholds were economically viable.

The synchrony of common natural enemy populations with potato mirid and bluegreen lucerne aphid populations was evaluated using correlation analysis of data collected during the 1994-95 Canterbury survey season. Although some natural enemy populations showed synchrony with bluegreen lucerne aphid (e.g., ladybird, *Coccinella undecimpunctata* L. and lacewing, *Micromus tasmaniae* [Walker]) and potato mirid nymphs (harvestman, *Phalangium opilio* L.), they were unable to prevent bluegreen lucerne aphid or potato mirid densities increasing to economic injury levels.

The development of a pest management programme for white clover seed production taking into account crop agronomy, growing practices and changes in the industry is discussed.

Key words: Potato mirid (*Calocoris norvegicus* [Gmelin]), bluegreen lucerne aphid (*Acyrthosiphon kondoi* Shinji), white clover (*Trifolium repens* L.), pest phenology, damage, lambda-cyhalothrin, fluvalinate, pirimicarb, biological control, ladybird (*Coccinella undecimpunctata* L.), lacewing (*Micromus tasmaniae* [Walker]), harvestman (*Phalangium opilio* L.), sampling, thresholds, integrated pest management

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CHAPTER ONE

INTRODUCTION

This chapter outlines the important characteristics involved in white clover seed production in New Zealand. A general section is presented on the importance of white clover as a crop and pasture species within the New Zealand agricultural system, followed by crop management practices and specific details about plant phenology associated with plant assimilate partitioning and seed production. These are all fundamental areas that require understanding for the development and successful adoption of any resultant pest management strategy.

The second section outlines the pest and beneficial fauna in white clover crops found from previous studies and possible interactions between the two groups. This is followed by a brief review of possible control tactics and the main experimental objectives covered in this thesis.

The overall aim of this thesis was to determine which insect pests are likely to cause economic injury to white clover seed crops with a special emphasis on their synchrony with plant phenology, and to explore strategies for their management.

THE IMPORTANCE OF WHITE CLOVER IN NEW ZEALAND AGRICULTURE

New Zealand's pastoral industries produce high quality animal products that are internationally competitive. This competitiveness is based on the availability of high quality animal feed sources provided by the combination of favourable climate, the availability of improved grass and legume species and the advent of fertiliser topdressing. Add to this the uptake of many research innovations by farmers and the result is one of the most competitive pastoral agriculture systems in the world. The use of white clover (*Trifolium repens* L.) in pastures has provided the cornerstone for this competitiveness.

It is believed that the early cultivation of white clover can be traced back to the Netherlands in the 1600s and was introduced into England in the 1700s (Mather *et al.* 1996). White clover seed was

brought by the early European settlers to New Zealand in the 1800s and immediately displayed adaptability to its new environment. White clover has widespread adaptability in most soils and climates and can withstand grazing stress and interspecific plant competition better than other legumes (Caradus *et al.* 1996).

White clover is grown in New Zealand pastures because it has four major benefits. As a legume it fixes nitrogen, it improves sward quality, complements seasonal growth patterns of commonly used grass species (mainly perennial ryegrass, *Lolium perenne* L.) and improves forage intake and utilisation rates of grazing animals (Caradus *et al.* 1996).

Nitrogen Fixation

The potential nitrogen-fixation rates by *Rhizobium* bacteria species in the root nodules of white clover are in the range of 600-700 kg N/ha/year (Crush 1987). However, the presence of mineral nitrogen and factors which limit white clover growth (i.e., moisture stress, low soil fertility, grazing pressure, soil temperature, grass competition, and appropriate *Rhizobium* strains) can result in much lower nitrogen fixation rates (Caradus *et al.* 1996). As a result, annual nitrogen fixation levels from white clover in grazed pastures are extremely variable, ranging from 17 kg N/ha/year in infertile, unimproved hill pastures (Grant and Lambert 1979) to 380 kg/ha/year in intensively managed pastures (Rumball 1979). Increases of 3 to 4-fold in nitrogen-fixation at the lower end have been achieved with improved cultivars (Cooper and Chapman 1993).

Nutritive Value, Seasonal Growth Pattern, and Intake Rate

White clover is considered to be the highest quality component of grazed pastures because of its high feeding and nutritive value (Ulyatt 1981; Osbourn 1982; Giovanni 1990). Feeding value is an animal production response, quantified by liveweight gain (g/d) or milk yield (*l*/d) whereas nutritive value is a response per unit of feed intake. Thus feeding value is a function of both intake and nutritive value (Ulyatt 1973).

Comparisons of nutritional and chemical composition of white clover have shown higher concentrations of crude protein (or total N) and readily fermentable carbohydrates, but lower concentrations of lipids, water soluble carbohydrates (sugars), lignin, cellulose, and fibre, than perennial ryegrass (Ulyatt *et al.* 1977; Ulyatt 1984). White clover has higher concentrations of

calcium, phosphorus, magnesium, copper, zinc and cobalt (on non-deficient soils), but lower concentrations of sodium and selenium (on deficient soils) than perennial ryegrass.

White clover growth occurs later in summer and autumn complementing the spring growth of most temperate grasses. Summer moisture stress can, however, disrupt this complementary growth pattern in pasture systems (Harris 1987).

White clover has a lower resistance to chewing than grasses because it has less cell wall and the length to width ratio of fibres is lower (Minson 1990). The lower resistance to breakdown during eating and ruminating by grazing animals resulted in 10-35% higher intake (kg dry matter/d) of white clover compared with perennial ryegrass in stall-fed animals (Ulyatt *et al.* 1977; Rogers *et al.* 1979; Ulyatt 1981). In field studies, this advantage is, however, realised only when animals have a high nutrient demand, such as occurs during the rapid growth of young animals and during lactation (Penning *et al.* 1995).

The Financial Contribution of White Clover

Caradus *et al.* (1996) summarised the estimated importance of white clover to the New Zealand economy as follows. Average annual nitrogen fixation, attributable to white clover, is estimated at 1.57 million tonnes over the 13.5 million ha of New Zealand grasslands and is worth an estimated $1.49 billion. New Zealand's gross agricultural production from its pastoral sector is $8.86 billion (*New Zealand Official Yearbook 1994*), of which about two-thirds of this value is for pastoral products from lowland and downland regions. White clover's contribution to the total yield of pasture is estimated at 20%, with no adjustment for forage quality, giving a value of $1.33 billion. For most hill and high country pastures the white clover content would be lower contributing to an estimated 10% of total production to give a value of $0.22 billion. White clover seed production contributes approximately $25 million annually ($18 million in export receipts - New Zealand Department of Statistics Export report 1995), and clover honey production contributes $30 million annually (New Zealand Beekeepers Association). Thus the estimated total financial contribution of white clover to the New Zealand economy is $3.095 billion annually.

Globally, New Zealand is the major white clover production region, providing 50-55% of the global seed crop (Mather *et al.* 1996). The majority of white clover seed (approximately 95%) is

produced in the Canterbury region. One cultivar, Grasslands 'Huia' (public cultivar[1]), has dominated the world white clover seed market for many years and it still remains the world's major cultivar by volume. However, in the last 10 years its position has come under increasing pressure from New Zealand and international proprietary cultivars[2] (Table 1).

Table 1. Seed production area for public cultivars, New Zealand and overseas proprietary cultivars for seasons 1990-91 to 1994-95 (MAF Seed Certification Statistics) (from Clifford 1997).

Seasons	Cultivar Type									Total area (ha)
	New Zealand Publics			New Zealand Proprietaries			Overseas Proprietaries			
	Area (ha)	% of Total	Yield (kg/ha)	Area (ha)	% of Total	Yield (kg/ha)	Area (ha)	% of Total	Yield (kg/ha)	
1990-91	9898	82	385	722	6	343	1396	11(17)*	327	12016
1991-92	12283	73	381	1492	9	194	2930	18 (27)	420	16705
1992-93	12271	77	284	867	5	438	2803	18 (23)	214	15941
1993-94	12607	81	244	1071	7	234	1921	12 (19)	180	15599
1994-95	10149	75	297	1540	11	276	1856	14 (25)	265	13545
1995-96	8807	63	302	2545	18	255	2671	19 (37)	287	14023
Means	11003	75	315	1373	10	290	2262	15 (25)	282	14638

* value in brackets refers to the total proprietaries.

THE GROWING OF WHITE CLOVER SEED CROPS

Cultivar Development

The identification of white clover strains and ecotypes began in the 1920s and resulted in the commercialisation of New Zealand Certified White Clover. This was successively developed through to the 1950s and culminated in the release of Grasslands Huia (although not named as such until 1964), a general-purpose cultivar with widespread adaptation (Williams 1983).

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[1] Public cultivars are cultivars bred by Grasslands (New Zealand Pastoral Agriculture Research Institute Limited, AgResearch) and maintained by Grasslands as a pure seed line. The grower does not pay royalties, which contributes to the reluctance to change to proprietary cultivars. [1] Proprietary cultivars refer to cultivars bred by Grasslands (New Zealand Pastoral Agriculture Research Institute Limited, AgResearch) and grown on exclusive licence by seed companies who then pay Grasslands a royalty for every kg seed produced. Grasslands maintains the purity of the seed line.

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The need for improved winter clover growth lead to the incorporation of Spanish genetic material and the development of Grasslands Pitau in the 1970s (Barclay 1969). Acknowledgement that different white clover types were required for different stock classes and management systems resulted in the breeding of Grasslands Tahora for set-stocked wet hill country (Williams 1983), and Grasslands Kopu for rotationally-grazed dairy pastures (van den Bosch *et al.* 1986). Other cultivars have been developed for the different climatic conditions throughout the country; Grasslands Demand for Southland pastures (Widdup *et al.* 1989) and Prop for persistence in summer drought (Macfarlane and Sheath 1984).

Cultivar Change

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 it for the previous five seasons. The new crop must then be sown in no less than 30 cm spaced rows, as set out in the 1993-94 Seed Certification 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 20 overseas cultivars are now multiplied in New Zealand for re-export. As a consequence, instead of having only the medium-leafed, main flowering-type Huia, we now have a full range from early (Grasslands Pitau, Prop) through to the late-flowering Grasslands Kopu, Aran and Tillman cultivars. These new cultivars have a flowering period starting at the beginning of October and extending through until mid-late February.

Growing Practices

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 (Table 1) and is sown in autumn with ryegrass, or in spring with a pea (*Pisium sativum* L.) or cereal crop (e.g., wheat *Triticum aestivum* L. or barley *Hordeum vulgare* L.) to be harvested after the companion crop in the following season. Huia can also be sown in autumn as a specialist crop in 15 or 30 cm spaced rows at a seeding rate of 3-5 kg/ha depending on time of sowing (Clifford and Batey 1983).

Clifford (1985b) found that out of three row spacings (15, 30 and 45 cm) potential dressed seed yield per ha at 30 cm was superior to that from the other spacings (1200, 1410, and 1180 kg/ha for

each row space, respectively). Each increase in distance between rows not only gave a higher stolon tip number per metre of row at harvest but also a higher percentage that had produced more inflorescences per stolon.

Maximising the seed yield potential for any particular cultivar also requires knowledge of the 'uniformly-distributed' stolon tip density needed at the time of closing the crop[3] to flower and an understanding of how management affects the speed of stolon formation and-or development, according to seasonal and site variations (Clifford 1987).

To achieve these aims New Zealand growers have adopted the following management practices, either singly or in combination (Clifford 1985a, 1985b, 1986a, 1986b):

1. Using autumn rather than previous spring sowings to curtail the over-development of stolons.
2. Doubling the distance between rows (15 cm to 30 cm), to ensure sufficient and evenly distributed space for floral expression.
3. Retaining normal seeding rate (3 kg/ha) at 30 cm row spacings, to promote competition between primary meristems at the expense of secondary stolon development.
4. Correcting any spring growth limitation by nitrogen rather than additional phosphorus application to ensure a more controlled vegetative response.
5. Controlling surplus spring growth by topping, silage or hay cutting techniques rather than grazing up to crop closure, to further limit secondary stolon development, while producing primary meristems from undue loss.
6. Adjusting time of crop closure to ensure the maximum use of space by reproductive growth.

Specialist white clover seed growers with access to irrigation in Canterbury achieve yields up to 900 kg/ha, and average 600-700 kg/ha in favourable seasons when crops are grown in spaced rows (Clifford and Batey 1983) compared with 250-400 kg/ha in undersown clover crops (McCartin 1985).

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[3] Growers usually graze their white clover crops with sheep to remove weeds and other crop debris. Crop closing refers to the removal of sheep allowing plant growth and seed yields.

ASPECTS INFLUENCING SEED PRODUCTION

Plant Phenology

White clover persistence in the pastoral system is dependent on stolon development and replacement (refer Figure 1). Stolon growth is also important in seed production. Axillary buds forming in the leaf axils (Erith 1924) can develop into either an inflorescence or a secondary stolon, but never both at the same site (Thomas 1961). The change in axillary bud initiation to either secondary stolon or inflorescence formation is controlled by the interaction of short day length and low temperature (Thomas 1980, 1981b). In New Zealand field conditions, axillary buds formed in September and October will generally produce inflorescences between October and January; buds produced at other times usually form secondary stolons (Thomas 1980, 1981b). Therefore crop management during the 'from sowing to crop closure period' aims to: (i) achieve a high ratio of reproductive to vegetative apical meristems, while (ii) maintaining sufficient space to ensure the most beneficial reproductive response possible, per unit area (Clifford 1987).

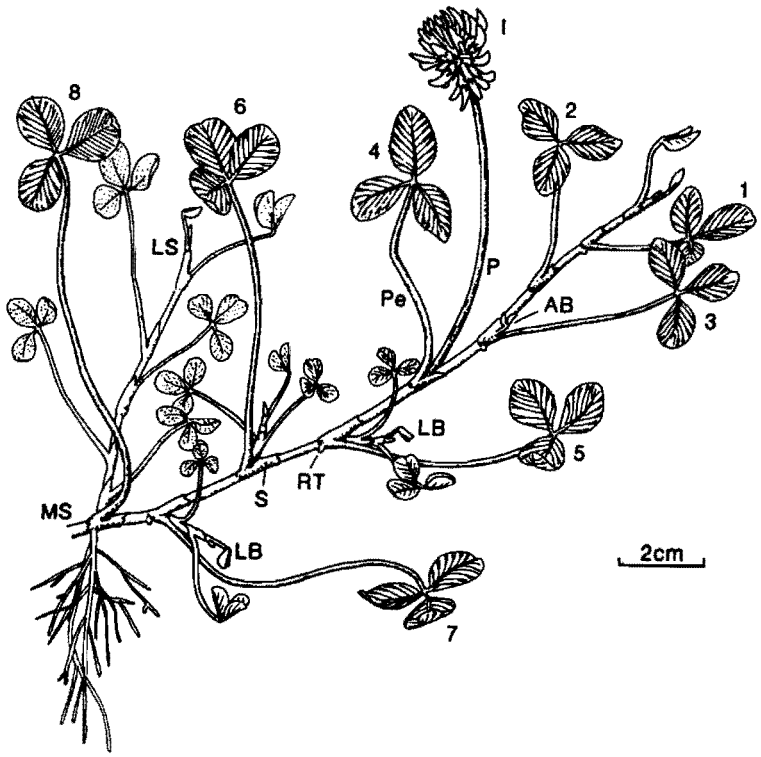

Figure 1. Drawing of main stolon (**MS**) of white clover, showing axillary buds (**AB**), lateral branches (**LB**), and a lateral or secondary stolon (**LS**). **S** = stipule; **Pe** = petiole; **RT** = nodal root primordium; **I** = inflorescence; **P** = peduncle. Emerged leaves on the main stolon, and the nodes bearing them, are numbered 1 to 8. (From R.G. Thomas 1987)

Inflorescence development occurs in an ordered sequence of floret formation, ovary, ovule and pollen grain formation, inflorescence opening, fertilisation, ovule maturation, and seed maturation (Thomas 1961, 1980). In field crops, development of inflorescences is greater closer to the stolon base. Commonly, no inflorescence occurs at the next youngest node, and a much delayed

inflorescence development occurs at the next successive node with usually a maximum of 2-3 inflorescences per stolon (Clifford 1985b). Actual inflorescence initiation by the plant is determined by photoperiod (Thomas 1981). The critical daylength for the long-day reaction was between 12 and 14 hours at 21°C in Huia clones (Thomas 1981). To maximise inflorescence initiation in New Zealand growers manage their Huia crops to have peak flowering on the longest day (22 December).

The crop's nutritional requirement over the reproductive phase must be understood to ensure the highest possible seed yields. Nutrition, in the broadest sense, means the photosynthetic input from leaves and stems, any translocation from other plant parts, and adequate moisture and minerals (Clifford 1986a). Therefore, the extent to which the crop environment can be modified, consistent with obtaining the best compromise between vegetative and dependent reproductive growth, will ultimately determine seed yield.

Plant Stresses

Site radiant energy levels and, for the most part, soil fertility are inflexible. Therefore, the only way to manipulate any deleterious effects of soil fertility on growth is to limit the soil moisture availability for plant nutrient uptake (Clifford 1986a).

In general, limiting the soil moisture reduces leaf size which, in turn, results in more leaf-associated inflorescences with lower floret numbers and higher resultant seed yields per unit area (Clifford 1985a). Care must be taken to ensure that the plant's wilting point is not reached, thereby severely limiting photosynthetic activity (Hagen *et al.* 1957). Although prolonged, moisture stress can limit later leaf development, Clifford (1985a) showed that high soil moisture increased leaf size (i.e., the crop produced more vegetative growth), and that these large-leafed crops supported far fewer inflorescences than small-leafed crops, giving lower seed yields. Therefore, the lower numbers of large leaves required to both form and maintain a mature canopy may also reduce the potential expression of florally initiated nodes (Clifford 1986b).

The soil moisture needed for maximum seed yields, therefore, is less than that needed for maximum vegetative growth. Hagan *et al.* (1957) found that, for Ladino white clover, most inflorescences were formed when the soil moisture available to plants was maintained at 25% field capacity.

Assimilate Partitioning

Plant life depends on respiration and transpiration for survival. If a plant is severely stressed, these will be the last two metabolic processes to receive assimilates. However, given favourable conditions, white clover plants partition assimilates first to vegetative growth and then reproductive growth (Clifford 1987; Clifford & Baird 1993).

Reproductive growth and assimilate distribution can be further prioritised as follows: first, to inflorescence development; second, to the formation of ovules; third, to the formation of pollen and lastly to the secretion of nectar. Once an inflorescence has been initiated at the leaf axil it becomes part of the plant's vegetative growth. That is, the plant is committed to inflorescence development over seed production or reproductive growth stage (Figure 2). The utilisation of reproductive potential is determined by the surplus of assimilate not required for vegetative growth. While pollen, once produced, is independent from plant provisioning, the processes involved in ovule development up to the formation of the seed coat are determined by assimilate provisioning. If provisioning is reduced due to some stress factor at the point of seed fill and after seed coat formation then overall 1000 seed weight[4] diminishes within ovules to a base level after which abortion of the latest formed ovules occurs (Figure 2).

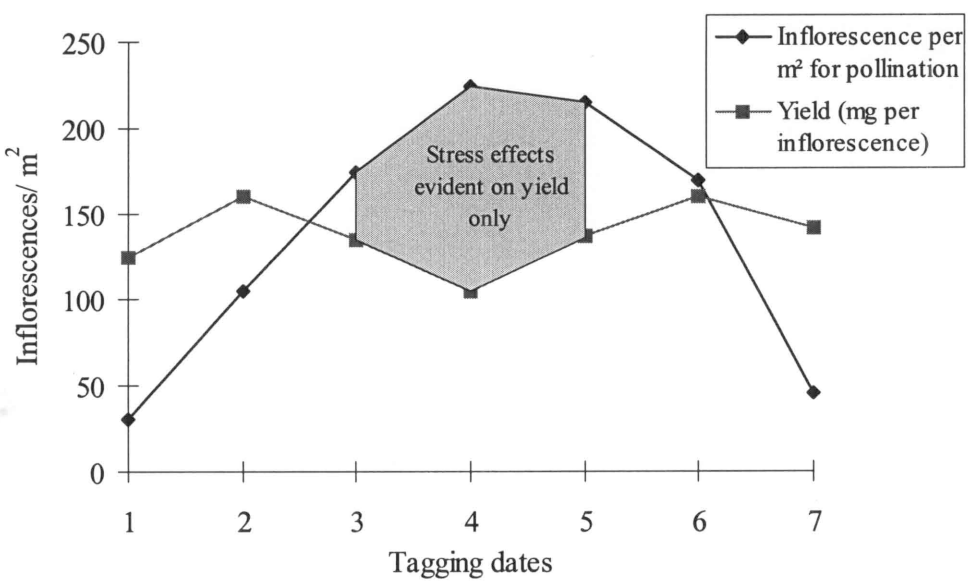

Figure 2. Inflorescences available for pollination and soil moisture stress effects on yield per inflorescence at each tagging date (mean of 4 replicates). Sampling date 1 = 5 Dec. '83; 2 = 12 Dec.; 3 = 19 Dec.; 4 = 26 Dec.; 5 = 2 Jan. '84; 6 = 9 Jan.; 7 = 16 Jan (from Clifford 1987).

[4] Thousand seed weight refers to the weight of one thousand white clover seeds and is used as a measure of seed quality. The heavier the seed the more stored reserves it possesses and therefore the stronger the resultant seedling produced. Good quality seed will have a thousand seed weight > 0.6 g.

Pollination

Cross pollination, as promoted by foraging bees (mainly domesticated honey bees, *Apis mellifera* L. and feral bumble bees, *Bombus* spp.) is fundamental to white clover reproduction. Therefore, it is necessary to understand the process of nectar secretion and thereby bee visitation. Honey bees are effort-reward driven. The more pollen and/or nectar to be harvested the higher the incidence of bee visitation. In red clover, nectar secretion depends on a carbohydrate surplus over and above that required for growth, respiration and other concurrent processes (Shuel and Paterson 1952). Therefore the practices, already outlined, for maintaining a good balance of nutrients with growth must also be conducive to nectar secretion. Thus crop attractiveness to pollinators is also a function of management practices to maximise inflorescence density and thereby yield, as verified by the observations of Johnson (1946). He found that white clover growing on light, sandy and soils sloping towards the sun gave superior nectar-flows to those on clay or flat soils. Both cloud cover (low radiant energy) and cool winds also reduced nectar secretion. Once pollination occurs the requirement for nectar secretion is lost with the assimilate source being transferred to provision the developing ovules. It is noted that insect pests are also effort-reward creatures, many seeking this concentrated carbohydrate source even prior to excretion as nectar (e.g., potato mirid, *Calocoris norvegicus* [Gmelin]).

Plate 1. Honey bee foraging from a white clover inflorescence. The recommended stocking rate is 1 hive/3 ha (Montgomery 1983).

PEST AND BENEFICIAL ARTHROPODS ASSOCIATED WITH WHITE CLOVER SEED CROPS

Until recently, the primary insect pests associated with white clover seed crops were two species of clover casebearer moth, *Coleophora mayrella* (Hübner) (banded casebearer, which was first recorded on Banks Peninsula in 1922), and *C. alcyonipenella* (Kollar) (whitetipped casebearer) first recorded in Hastings in 1944 (Pearson 1982; French 1972). Clover casebearer larvae feed directly on the clover seed within the pod and have destroyed more than 60% of the seed set within a crop (Pearson 1982). French (1972) concluded that insecticides should only be used if economically necessary and that their use should be kept to a minimum to reduce harm to bees. The clover casebearer moths are the only white clover pests for which an insecticide action threshold has been developed (French 1971).

During the period 1952 to 1969, 23 parasitoids were introduced into New Zealand as potential biological control agents for clover casebearer moths (Pearson 1989). Of these, *Bracon variegator* Spinola (Hymenoptera: Braconidae) and *Chrysonotomyia trifolii* (Erdös) (Hymenoptera: Eulophidae) were successfully introduced from Europe and released in 1961-68 and 1961-69, respectively. The parasitoids prefer whitetipped casebearer and attack the cased fourth instar larvae (Early 1984). Although the smaller *C. trifolii* is more effective at controlling clover casebearer, the action of both parasitoids had markedly reduced clover casebearer populations by the late 1970s to the extent that seed growers no longer applied insecticides for their control. The application of these insecticides would have undoubtedly controlled other insect pests, however, since the reduction in insecticide use in white clover crops there has been an increase in inflorescence injury thought to be caused by the feeding of hemipteran pests.

Until recently, uneconomic white clover seed yields from second-harvest crops[5] were mainly associated with an explosion of resident clover casebearer populations that carried over from the previous season. Since the reduction in clover casebearer numbers and the introduction of row-spaced crops, there has been an increase in the area of white clover crops taken for two or more consecutive seed harvests. The insect pest and arthropod predator fauna has not been studied exclusively in white clover seed crops to determine the numbers and distribution of potential insect pests that may have an adverse impact on crop longevity and seed yield potential.

Table 2. Pest and beneficial arthropods collected from white clover crops in Canterbury during the 1993-94 season (from Schroeder 1995).

Common Name	Scientific Name
Insect Pests	
Potato mirid	*Calocoris norvegicus* (Gmelin)
Bluegreen lucerne aphid	*Acyrthosiphon kondoi* Shinji
Meadow spittlebug	*Philaenus spumarius* (L.)
Brown shield bug	*Dictyotus caenosus* (Westwood)
Wheat bug	*Nysius huttoni* White
Lucerneflea	*Sminthurus viridis* (L.)
Garden springtail	*Bourletiella hortensis* (Fitch)
Clover casebearer moths	*Coleophora mayrella* Hübner and *C. alcyonipenella* (Kollar)
Australian crop mirid	*Sidnia kinbergi* (Stål)
Arthropod Predators	
Elevenspotted ladybird	*Coccinella undecimpunctata* L.
Pacific damsel bug	*Nabis kinbergii* (Reuter)
Tasmanian lacewing	*Micromus tasmaniae* (Walker)
Large hover fly	*Melangyna novaezelandiae* (Macquart)
Small hover fly	*Melanostoma fasciatum* (Macquart)
Carabid beetles	several species
European harvestman	*Phalangium opilio* L.
Money spiders	*Lepthyphantes tenuis* (Blackwell)
Wolf spiders	*Lycosa hilaris* Koch

Schroeder (1995) identified 10 insect pest species and nine potential arthropod predators associated with white clover seed crops from suction sampling of seven crops around the Lincoln (Canterbury) area (Table 2). However, parasitoids that were collected in samples were not identified or counted.

Other pests associated with white clover seed crops and pastures are porina, *Wiseana* spp.; grass grub, *Costelytra zealandica* (White); and grey field slug, *Deroceras reticulatum* (Müller). These pest species and their impact on white clover seed production have not been included in this study.

Of the 10 insect pest species collected in a preliminary white clover seed crop survey, potato mirid (PM) and bluegreen lucerne aphid (BGLA) were the most prevalent and most likely to cause economic injury to the developing inflorescences with resultant seed yield reductions (Schroeder 1995). The numbers of several other insect pests (e.g., brown shield bug and Australian crop

[5] Second-harvest crops refers to crops that have been retained to take a further crop in the second reproductive year.

mirid) increased later in the season at or after seed set and were, therefore, not considered to be economically important.

RATIONALE FOR THESIS

From preliminary studies carried out during the 1993-94 season (Schroeder 1995), it was evident that further research was required to identify the economically important insect pests and their impact on white clover plant growth and seed production. Specifically, the following aspects were considered to be important:

- It was necessary to extend an initial crop survey to cover a wider range of Canterbury growing regions to determine seasonal variations that may occur between these regions which may influence crop and pest phenology. Regional differences could then be included in pest management strategies.
- The key insect pests still required identification and their temporal and spatial distribution within white clover crops determined, to develop appropriate management programmes.
- While determining the key insect pests, it was necessary to determine what levels were required to cause economic damage (threshold development).
- Once the key pests were identified, it was essential to link crop and insect pest phenologies to establish which plant developmental stages were most vulnerable to insect feeding injury.
- Most of the previously used insecticides (Wightman and Whitford 1982) are no longer commercially available and have been replaced with other chemicals. These chemicals require testing against the key pests in white clover seed crops.
- The distribution and abundance of the natural predator fauna in white clover was unknown and required study to determine what synchrony and level of control it may have on the key insect pests.

Main Aim

The main aims of the research in this thesis were first, to identify the key economic pests in white clover seed crops by studying the interactions between plant and insect pest phenologies; second, to quantify the effect of selected pests on white clover seed production; and third, to determine the effectiveness of insecticide applications for controlling the pests and fourth, to determine the synchrony of potential natural enemy populations with those of the key insect pests. Specific objectives of the research are as follows.

- ***To assess the spatial and temporal distribution of insect pests within white clover crops grown in different Canterbury regions (Monitoring white clover seed crops in the Canterbury region).***

- ***To study the spatial and temporal distribution of insect pests within a single white clover crop and develop a crop sampling programme (Intensive field monitoring).***

- ***To establish the influence of strategic timing and placement of three insecticides within a crop environment (Evaluation of the timing and placement of insecticide application in white clover seed crops).***

- ***To determine the impact of bluegreen lucerne aphid on different plant growth stages and different potato mirid intensities on inflorescence expression and resultant seed yields within field cages (The effect of potato mirid and bluegreen lucerne aphid on white clover seed production in field cages).***

- ***To assess the abundance and distribution of natural predators within white clover crops and their synchrony with the key insect pests (Synchrony between predatory arthropods and insect pests in white clover seed crops).***

CHAPTER TWO

MONITORING WHITE CLOVER SEED CROPS IN THE CANTERBURY REGION

INTRODUCTION

From a preliminary survey of several Lincoln white clover seed crops during 1993-94, Schroeder (1995) found that bluegreen lucerne aphid (BGLA, *Acyrthosiphon kondoi*) occurred at the highest densities (>300/m^2) throughout the fields, while potato mirid nymphs (PM, *Calocoris norvegicus*) occurred predominantly in the field margins and later as adults throughout the crop. Because of the large numbers of BGLA present, farmers were more likely to apply insecticides for its control than for any other insect pests present.

Schroeder and Chapman (1995) concluded that more effective pest control could be achieved through better timing of insecticide applications and that identification of the key economic insect pests was still needed. Although Canterbury produces 95% of New Zealand's white clover seed, the associated arthropod fauna has never been comprehensively identified or quantified to identify potential insect pests, nor have any regional differences in their spatial and temporal distributions been investigated.

The soils of the Canterbury Plains are created by alluvial deposits carried by the braided river systems that run across its surface (Figure 3). As a consequence, there is a significant soil variability between the different growing regions that range from the shallow soils in Darfield (e.g., Lismore stony silt loam) to deeper soils (e.g., Templeton and Wakanui silt loams) associated with coastal (e.g., Timaru and Southbridge) and river bank deposits (e.g., Barrhill fine sandy loam) (Appendix A). It is also common to find soil depth varying within each field thus causing some areas of a field to dry out prematurely in early summer.

A detailed crop monitoring survey of pest and natural enemy arthropod populations was conducted during 1994-95 growing season on 24 first-harvest Grasslands Huia white clover seed crops in different Canterbury growing regions. The survey was repeated during 1995-96 in 5 of the previous 8 growing areas. This chapter examines the data collected from these crops, with the emphasis on determining the abundance and distribution of different insect pests during crop development.

MATERIALS AND METHODS

Field Selection and Location

1994-95 season

Three first-harvest Grasslands Huia crops were selected from each of the following areas: Ashburton/Barrhill, Coastal Ashburton, Darfield, Lincoln, Methven, Sheffield, Southbridge, and Timaru. Each field was suction sampled for arthropods every two weeks from 15 November, 1994, until harvested (last sample at Southbridge 9 February) (Table 3) (Figure 3). Travel distances between growing areas and the time taken to sample each crop (approximately one hour) made it impossible to sample all 24 crops on the same day. Therefore, all crops in the Darfield, Sheffield, Lincoln and Southbridge areas were sampled during one week, followed by crops from the other areas during the next week. The data collected from each pair of weeks were analysed as one sampling date and are presented in the results (Figures 6 to 10) by the mid-date of the two weeks. Field sizes averaged 8 hectares (range 3 to 13.3 hectares). In preliminary field sampling during the 1993-94 season, Schroeder (1995) found that PM was likely to invade from the crop edge. Transects were, therefore, located in each crop from a weedy verge into the crop, specifically to study the invasion of PM from such margins. Suction samples were collected at the crop's 'edge', 15 m, 30 m, 'halfway' between 30 m and the crop 'centre', and the crop 'centre' to determine the distribution of insect pests and their arthropod predators within the crop.

The insect suction sampler was a two-stroke Stihl™ (BG72) leaf blower motor mounted on a collection container and covered a 201 cm^2 suction area and was similar to the sampler described by Arnold (1994). There were 40 suction samples (0.804 m^2) taken at each sampling position along the transect. Each suction was taken over a 2-3 second period and samples were collected during

the day (10 am to 6 pm). The samples were collected in 250 ml plastic pottles (at 10 suctions per pottle), and placed in a freezer (-20^{0}C) for later identification and counting of the arthropods. Each pottle was assessed separately, but there were no significant differences found in insect numbers between the four pottles collected from each sampling position, therefore data at each sampling position were pooled.

Table 3. Location and management of the white clover seed crops monitored in Canterbury during 1994-95.

Growing region	Clover sown with	Crop area (ha)	Verge type	Verge aspect	Harvest date
Ashburton/Barrhill					
Foster	spring barley	3	weedy farm track	N-E	9 Jan
Irwin	spring barley	8	weeds and gorse hedge	S	25 Jan
Macfarlane	spring barley	11	weedy roadside	N-E	20 Jan
Coastal Ashburton					
Bennett	spring peas	12	pine hedge and weeds	N-E	1 Feb
Digby	spring barley	13	weedy farm track	W	17 Feb
Wilson	autumn wheat	12	weedy roadside	S	17 Feb
Darfield					
Adams	autumn ryegrass	9	weedy roadside	N-W	12 Jan
Gillanders	spring peas	8	weedy water race	S	24 Jan
Gilmour	spring rape	4	weeds and gorse hedge	E	9 Feb
Lincoln					
Bussell	autumn ryegrass	8	weedy farm track	W	3 Jan
Macartney	autumn ryegrass	5	grass and weeds	W	16 Jan
Morrish	spring barley	6	grass and weeds	N-E	25 Jan
Methven					
Coppard	spring radish	13	grass and weeds	E	13 Feb
Ridge	spring peas	12	weedy roadside	N	1 Feb
Wright	spring barley	7.5	weedy farm track	W	24 Jan
Sheffield					
Cullen	autumn w/c	4.5	weedy roadside	W	25 Feb
Earle	spring barley	10	weeds and gorse hedge	N	25 Feb
Jenkin	autumn ryegrass	7.5	weedy roadside	E	24 Jan
Southbridge					
Heslop	autumn w/c	6.4	weedy roadside	N	26 Feb
Lemon	autumn w/c	7.3	weedy fenceline	W	14 Feb
Lowery	autumn w/c	8	weedy water race	W	14 Feb
Timaru					
Howey	spring barley	13	shelterbelt and weeds	E	15 Feb
Kelliher	autumn ryegrass	11	weedy farm track	S	12 Feb
White	autumn ryegrass	7	weedy farm track	E	17 Feb

White clover seed was under-sown[6] in all crops except for Cullen, and the three Southbridge crops, where clover was sown alone (refer Table 3).

1995-96 season

During 1995-96, the number of growing regions was reduced to five and three first-harvest Grasslands Huia white clover crops were selected in each region (Table 4). All crops were suction sampled every two weeks at six positions ('edge', 2, 4, 8, 16, and 32 m into the crop) to determine the spatial and temporal distribution of insect pests and their natural enemies. Due to the lower number of crops, compared with the previous season, all the crops were sampled during one week, but are presented in the results as the mid-date of the two week period to determine differences between seasons. Sampling during the 1995-96 season started two weeks later than the previous season. The higher concentration of sampling positions near the crop edge was a development from the previous season to determine the distance of PM invasion into the white clover seed crop.

[6] Under-sown refers to a two-season cropping system where a grain (wheat and barley) or other seed crop is sown to produce seed for the coming season and white clover seed is sown at the same time to be taken as a seed crop in the following season.

Table 4. Location and management of the white clover seed crops monitored in Canterbury during 1995-96.

Growing region	Sown with	Crop area (ha)	Verge type	Verge aspect	Harvest date
Coastal Ashburton					
Bennett	spring peas	8.5*	weedy farm track	N-W	6 Feb
Digby	spring barley	9.5*	weedy farm track	W	17 Feb
Wilson	spring barley	18.5*	weedy roadside	S	17 Feb
Barrhill					
Irwin	autumn w/c	7.7	weedy farm track	E	14 Feb
Macfarlane 1	spring peas	14.0	weedy roadside	S	6 Feb
Macfarlane 2	winter wheat	20.0	weedy roadside	N-E	5 Feb
Darfield					
Adams	autumn ryegrass	9.5	weedy roadside	N-W	19 Jan
Gillanders	spring peas	6.5	weedy roadside	N	19 Jan
Gilmour	autumn ryegrass	8.0	weedy farm track	S	14 Feb
Methven					
Coppard	spring radish	16.6*	weedy roadside	S	17 Feb
Ridge	autumn ryegrass	9.0*	weedy farm track	W	12 Feb
Wright	autumn ryegrass	6.5	weedy farm track	N	17 Feb
Timaru					
C. Kelliher	autumn ryegrass	10.0	weedy roadside	W	5 Feb
J. Kelliher	autumn ryegrass	4.4	weedy fenceline	W	5 Feb
Oldfield	autumn ryegrass	8.0	weedy roadside	E	Not harvested

* crops that were irrigated during the season.

Long term weather data (rainfall and air temperature) are presented from weather stations located in or close to the main growing regions (Figure 3).

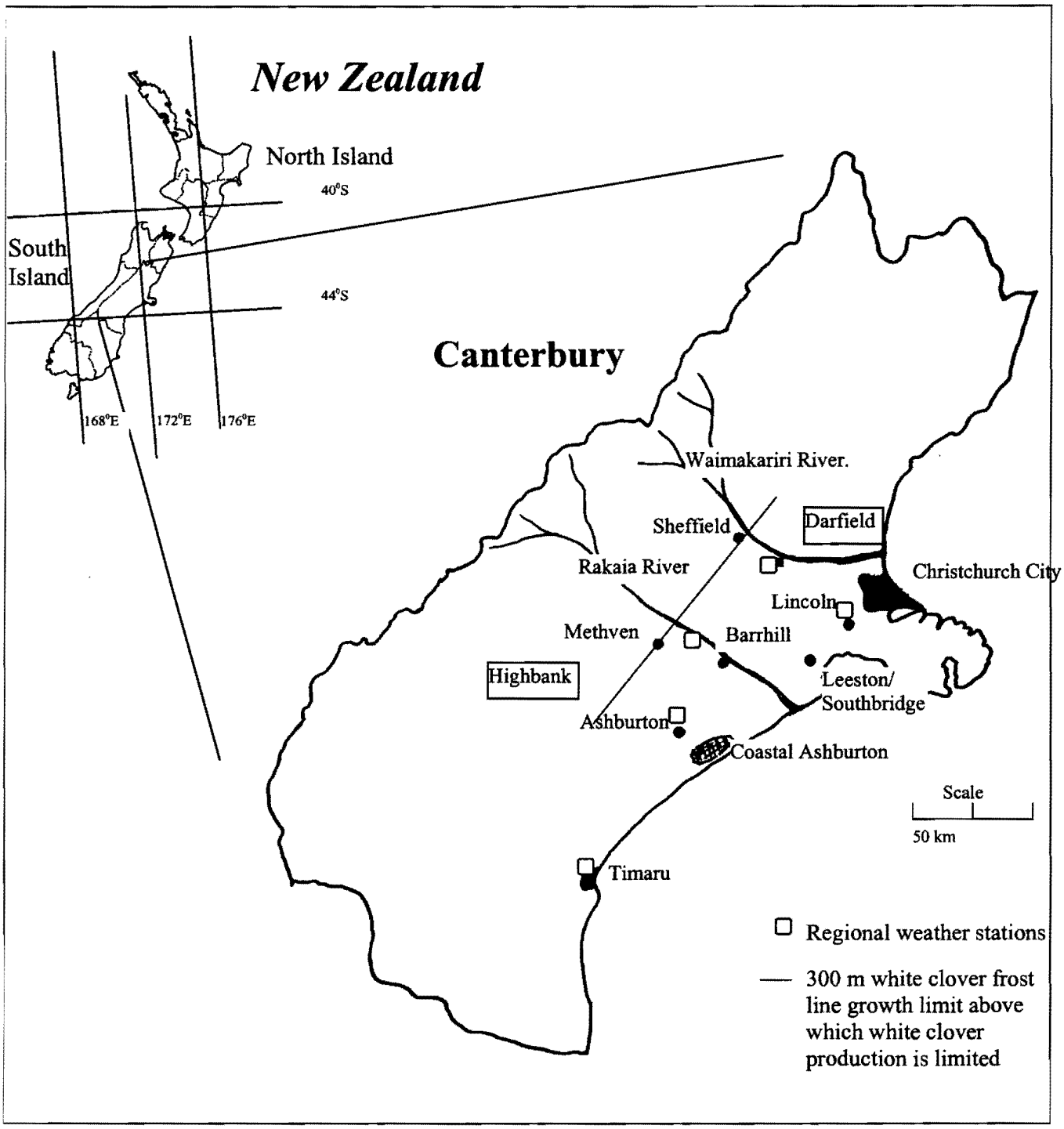

Figure 3. Map of New Zealand illustrating the Canterbury region and the crop monitoring sites used in the 1994-95 and 1995-96 seasons.

Despite latitudinal and altitudinal differences there does not appear to be much variation in the air temperatures recorded from the different white clover growing regions of Canterbury, however, rainfall ranged between 40 to 90 mm (Figure 4).

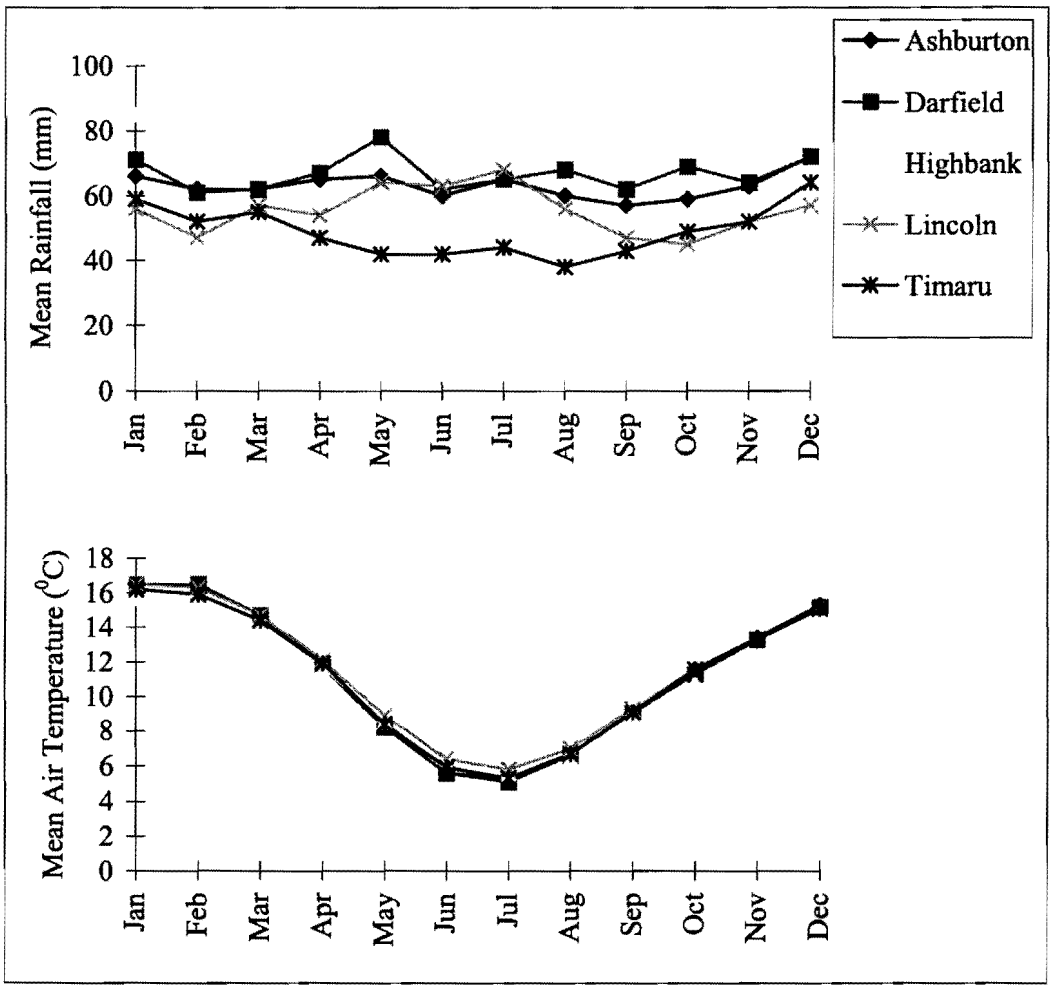

Figure 4. Long-term (30 year) monthly means for rainfall and air temperatures in the crop monitoring sites.

Inflorescence and Seed Harvest Sampling

During each season, inflorescence counts were taken every two weeks to determine the flowering pattern within each crop. Inflorescences that had florets available for bee pollination were counted within a 0.25 m^2 quadrat (Plate 6, Chapter 3). However, the two-week interval between counts made it difficult to accurately determine the flowering patterns. Weekly counts would have improved the accuracy of predicting peak flowering. The lack of accuracy was compounded by the

large variability of plant growth within and between fields, which was modified by a number of variables (e.g., soil type, crop establishment, weed competition) and seasonal weather patterns.

Harvest samples (5 x 0.45 m) were collected by rotary lawn mower at each of the sampling positions before to the grower harvested the crop (refer Tables 3 and 4 for harvest dates). Unfortunately, the white clover crops of Bussell and Kelliher (1994-95 season) were machine harvested before harvest samples could be collected. The sample areas were selected for their good clover growth and represented areas where high insect numbers and seed yields were likely to be collected. Because of the non-random selection of sampling areas, the resultant data is likely to show a bias towards a uniform, high yielding crop and not be representative for the whole crop. In most crops a desiccant herbicide ('Reglone', 200 g/litre diquat, Crop Care N.Z. Ltd.) was applied to the harvest sample areas to prepare them for harvesting. The harvested samples were placed in large paper bags and oven dried at 80 ^{0}C for several days until completely dry. Dry weights (of the harvested sample) were recorded before the samples were threshed for seed using a belt thresher. Each sample was then put through a 'Seed Bro' (USA) vertical air-draft separator set to collect the good quality seed (1000 seed weight >0.6 g), consistent with commercial operations. Seed weights were recorded for later data analysis.

During 1995-96, a survey (Appendix B) was sent to the 15 participating growers to determine the importance of insect pest management within their growing practices. The survey was designed to identify the problems that growers experienced with insect pest management in their crops. This survey, in turn, helped develop the direction of the research contained within this thesis.

Analysis of Results

For statistical comparisons and significance testing, data for each species were analysed by a general analysis of variance model using a Poisson error distribution to normalise the data. The use of Poisson transformations assumes that the arthropod species collected were randomly distributed within the field. Analysis was carried out using the Genstat® for Windows statistical package (© Lawes Agricultural Trust, IACR, Rothamsted, U.K.). Seed yield data were analysed by general analysis of variance. Insect pest and yield data were compared between the different growing regions and between sampling positions within the white clover crops.

RESULTS

Slightly different surveys were conducted during two seasons, each season's data are considered separately. All natural enemy data collected during the two seasons have been combined with other field experimental work and presented in Chapter 6. The arthropod species collected in the suction samples are given in Table 5. Only the most abundant pest and beneficial arthropods (> $1/m^2$) are studied in detail.

Table 5. Insect pests collected in samples collected from Canterbury white clover seed crops during 1994-95 and 1995-96.

Common Name	Scientific Name	Adult	Immature
	Insect Pests		
Potato mirid	*Calocoris norvegicus* (Gmelin)	✓*	✓*
Bluegreen lucerne aphid	*Acyrthosiphon kondoi* Shinji	Counted as one*	
Meadow spittlebug	*Philaenus spumarius* (L.)	✓	✓
Australian crop mirid	*Sidnia kinbergi* (Stål)	✓	✓
Brown shield bug	*Dictyotus caenosus* (Westwood)	✓	✓
Wheat bug	*Nysius huttoni* White	✓*	✓*
Clover casebearer moths	*Coleophora mayrella* (Huebner)	✓	
	C. alcyonipenella (Kollar)	✓	

• refers to >$1/m^2$ of species collected in samples.

The two clover casebearer moth species and meadow spittlebug nymphs were collected in late November to early December, while Australian crop mirid and brown shield bug were collected later in the season when the main flowering period was over (Figure 5). Insect pest data (PM, BGLA, and wheat bugs) collected from all the growing regions have been combined for each sampling position and are presented in the following graphs. The data collected (PM, BGLA, and wheat bugs) from the three fields in each growing region were combined to determine differences in insect distribution from the edge into the crop and between growing regions. The regional differences are presented as a range, which gives the lowest and highest insect pest densities and the growing regions from which they were collected. The development of a sampling programme and the variables (e.g., sampling bias and accuracy) associated with the sampling methodology will be discussed in Chapter 3.

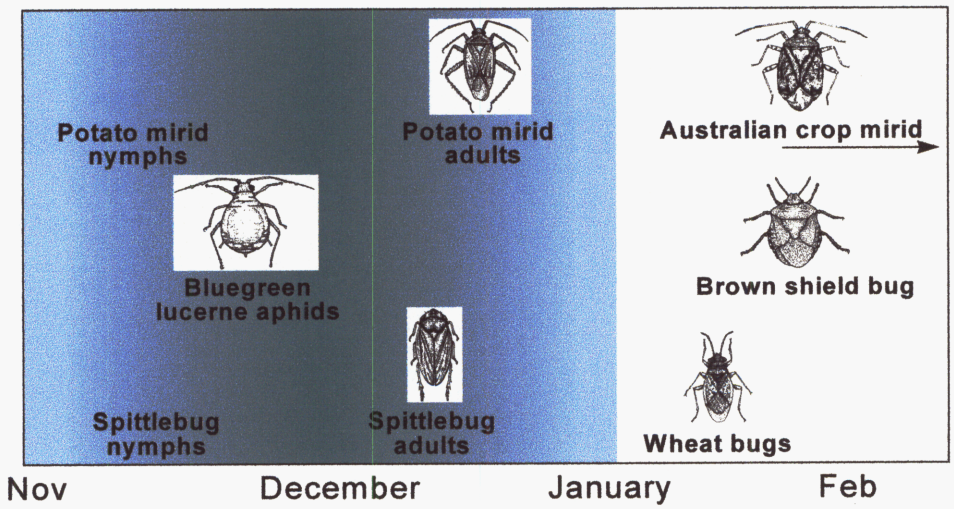

Figure 5. A graphical representation of the overall occurrence of insect pests (insects not to scale, refer Appendix C FAR Publication for descriptions) collected during 1994-95 and 1995-96. The shaded area indicates the overall flowering pattern (peaking in mid to late-December) of white clover crops grown in Canterbury.

Potato mirid nymphs

Plate 2. Fifth instar potato mirid nymph feeding on a developing white clover inflorescence. First and second instars are <2 mm and up to 6 mm long by the fifth instar.

Potato mirid nymphal densities were higher early in the season during inflorescence (mid-late November) development and decreased over time (Figure 6). PM nymphal densities were significantly ($P< 0.001$) higher in the 'edge' sampling positions during both the 1994-95 and 1995-96 seasons (Figure 6) reaching a maximum of 40 and 20/m^2 (respectively) in late November. There

were significant ($P < 0.001$) differences in PM nymph densities over time and between the different growing regions during both seasons. The highest overall 'edge' position densities, averaged over the season, were recorded in Methven (38 ± 1.8/m^2) and Timaru (13 ± 1/m^2) compared with Southbridge (1 ± 0.3/m^2) and Darfield (0.3 ± 0.2/m^2), during 1994-95 and 1995-96, respectively.

Third to fifth instar PM nymphs were the most commonly collected stages during both seasons.

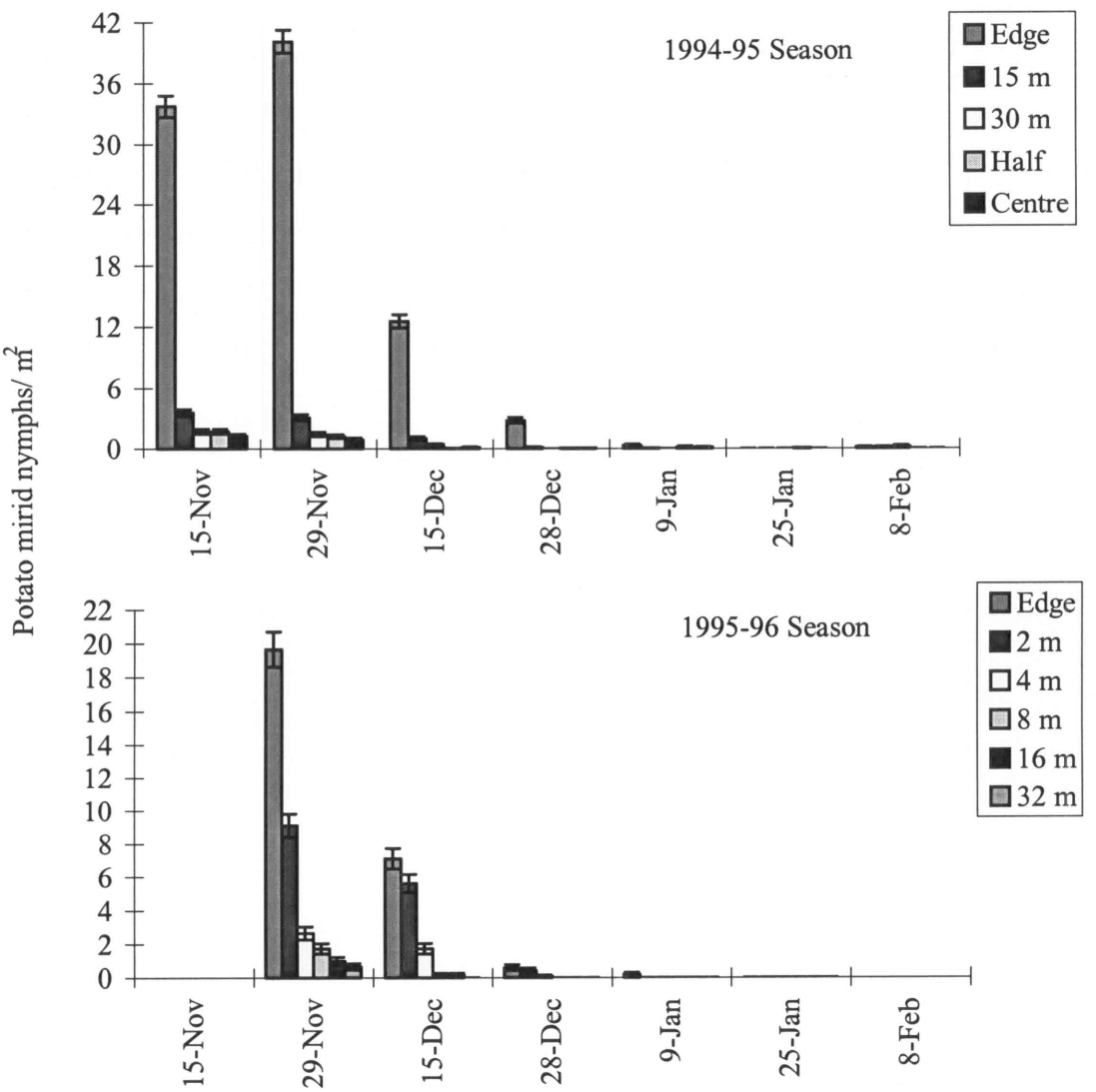

Figure 6. The density of potato mirid nymphs (± SEM) at different sampling positions in Canterbury white clover seed crops during the 1994-95 and 1995-96 seasons.

Potato mirid adults

Plate 3. Adult potato mirids are approximately 8 mm long and have well developed wings.

Fifteen percent fewer PM adults were collected compared with PM nymphs. The greatest density of PM adults occurred during the later stages of white clover inflorescence development and main flowering periods (mid December to early January). Significantly ($P< 0.001$) higher densities of PM adults were collected from sampling positions near the edge of the crop than those further into the crop (Figure 7). Overall, densities of PM adults at this position peaked during mid December (1994-95) at 5.7 ± 0.5/m^2 and during early January (1995-96) at 6.8 ± 0.8/m^2. There were significant ($P<0.001$) differences in the densities over time (both seasons) and between the different growing regions (1995-96 only). Their densities ranged from 0/m^2 (Ashburton/Barrhill) to 4.1 ± 0.6/m^2 (Timaru) during mid December in 1994-95 and from 0.2 ± 0.1/m^2 (Ashburton) to 5.0 ± 0.6/m^2 (Timaru) during early January in 1995-96.

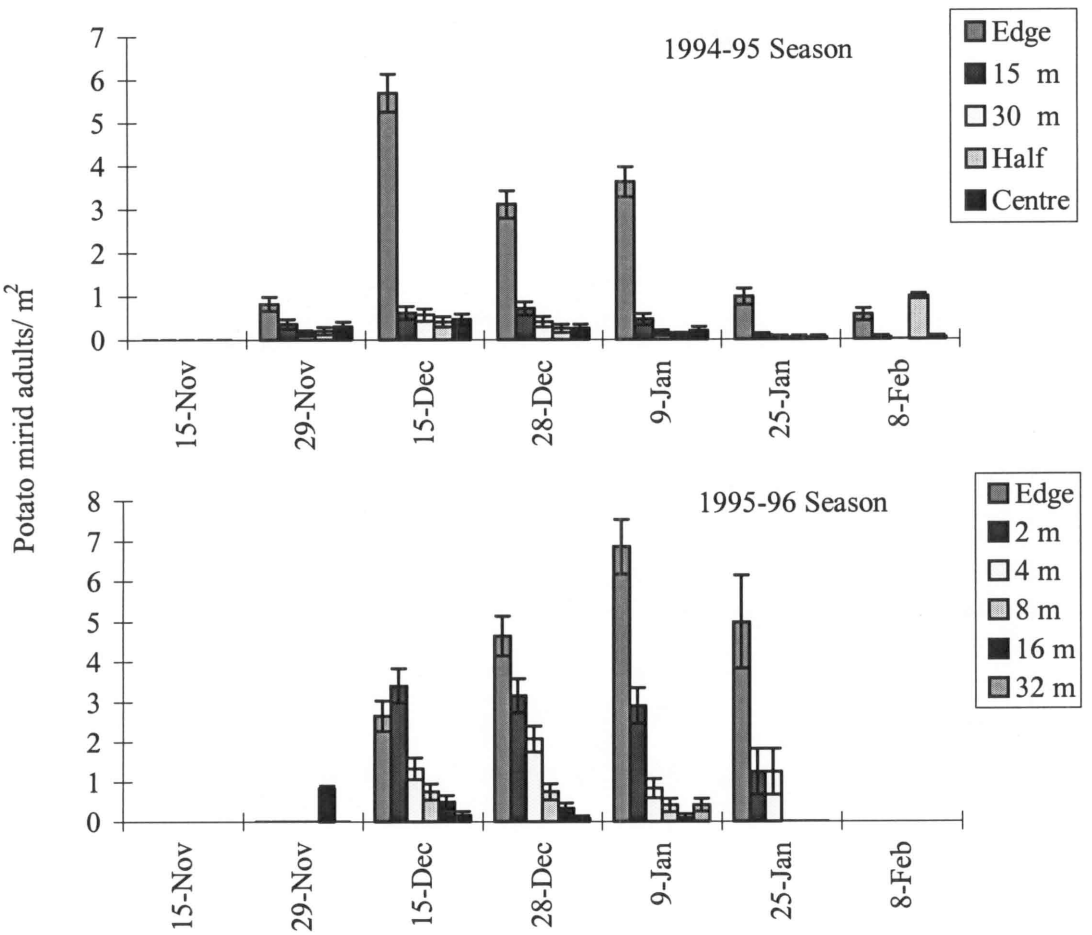

Figure 7. The density of potato mirid adults (± SEM) at different sampling positions in Canterbury white clover seed crops during 1994-95 and 1995-96.

Bluegreen lucerne aphid

Plate 4. Bluegreen lucerne aphid colony on a developing white clover inflorescence. Adults are 2-3 mm long.

Bluegreen lucerne aphid densities increased rapidly and peaked during early and main flowering of the white clover crops (Figure 5). When the data were pooled, their densities during both seasons were significantly ($P< 0.001$) different between sampling positions with fewer, generally, being collected at the 'edge' and greater densities further into the crop (Figure 8). BGLA densities peaked two weeks later during mid December in 1995-96 compared with 1994-95 (Figure 8). Overall, the maximum densities at these times were recorded at the 'centre' ($978 \pm 7/m^2$) and 16 m ($1394 \pm 11/m^2$) positions, respectively. The pooled BGLA densities were significantly ($P< 0.001$) different between the different growing regions for both seasons. These ranged from $134 \pm 3/m^2$ (Southbridge) to $1750 \pm 12/m^2$ (Ashburton/Barrhill) in 1994-95 and $266 \pm 4/m^2$ (Barrhill) to $2777 \pm 14/m^2$ (Darfield) in 1995-96, respectively.

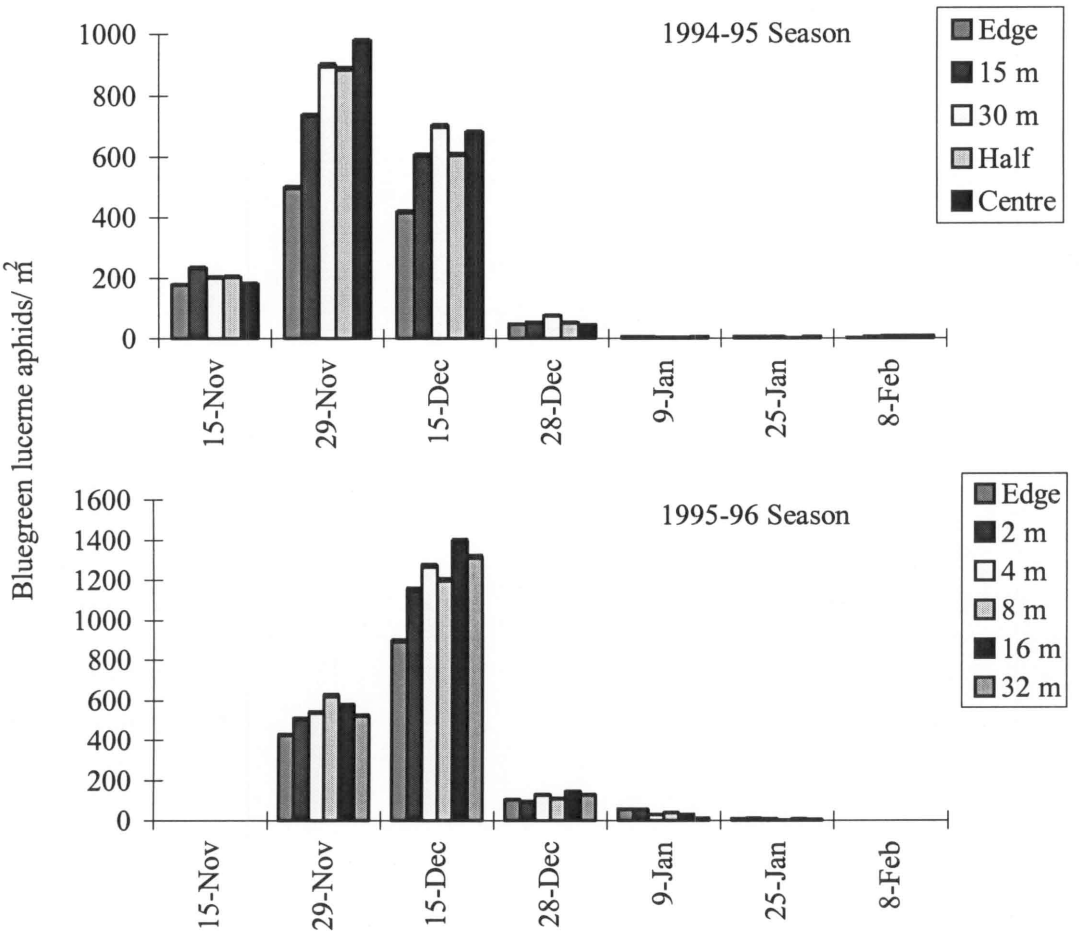

Figure 8. The density of bluegreen lucerne aphids at different sampling positions in Canterbury white clover seed crops during 1994-95 and 1995-96.

Wheat bug nymphs

Wheat bug nymphs occurred soon after the main white clover flowering period (Figure 9). The densities of wheat bug nymphs collected during both seasons were similar except in early January when high densities were found at the 'half' (> 350/m^2) and 'centre' (> 180/m^2) positions in Wilson's white clover crop in the Coastal Ashburton growing region. The density of wheat bug nymphs collected during early January ranged from 0 in Ashburton/Barrhill, Methven and Timaru to 117 ± 3/m^2 in Coastal Ashburton. There were significant ($P< 0.001$, 0.01) differences in wheat bug nymph densities between sampling positions during the 1994-95 and 1995-96 seasons, respectively and fewer were collected at the 'edge' position compared with other sampling positions (Figure 9). Visual assessments showed that wheat bug nymphs occurred in greater

densities in areas that had a lower clover plant density and open crop structure with areas of bare ground.

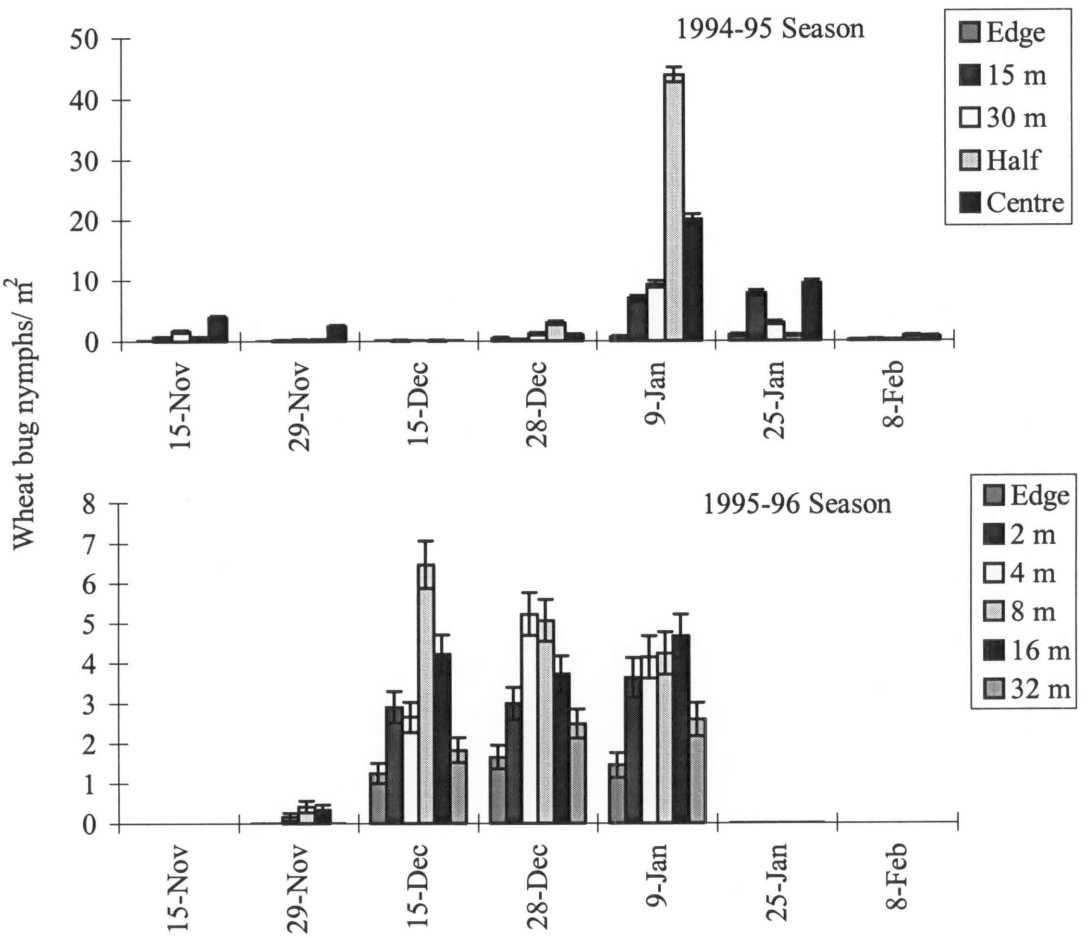

Figure 9. The density of wheat bug nymphs (± SEM) at different sampling positions in Canterbury white clover seed crops during 1994-95 and 1995-96.

Wheat bug adults

Adult wheat bug densities were greater after the main flowering period (Figure 10). Similar densities of wheat bug adults were collected during the two seasons, except for the 'half' and 'centre' positions in early January during 1994-95 (Figure 10). These higher densities of adults corresponded with the higher densities of wheat bug nymphs collected from Wilson's white clover crop (coastal Ashburton). Overall, wheat bug adult densities increased from the 'edge' into the crop and, in both seasons, adult densities peaked during early January after the main white clover flowering period (early to late December). During this period, the densities ranged from $0/m^2$

(Ashburton/Barrhill) to 69 ± 2/m^2 (coastal Ashburton) and from 0/m^2 (Darfield) to 13 ± 1/m^2 (Barrhill) during 1994-95 and 1995-96, respectively. Greater numbers of wheat bug adults were sampled from areas of sparse plant growth and bare ground (Plate 8, Chapter 4).

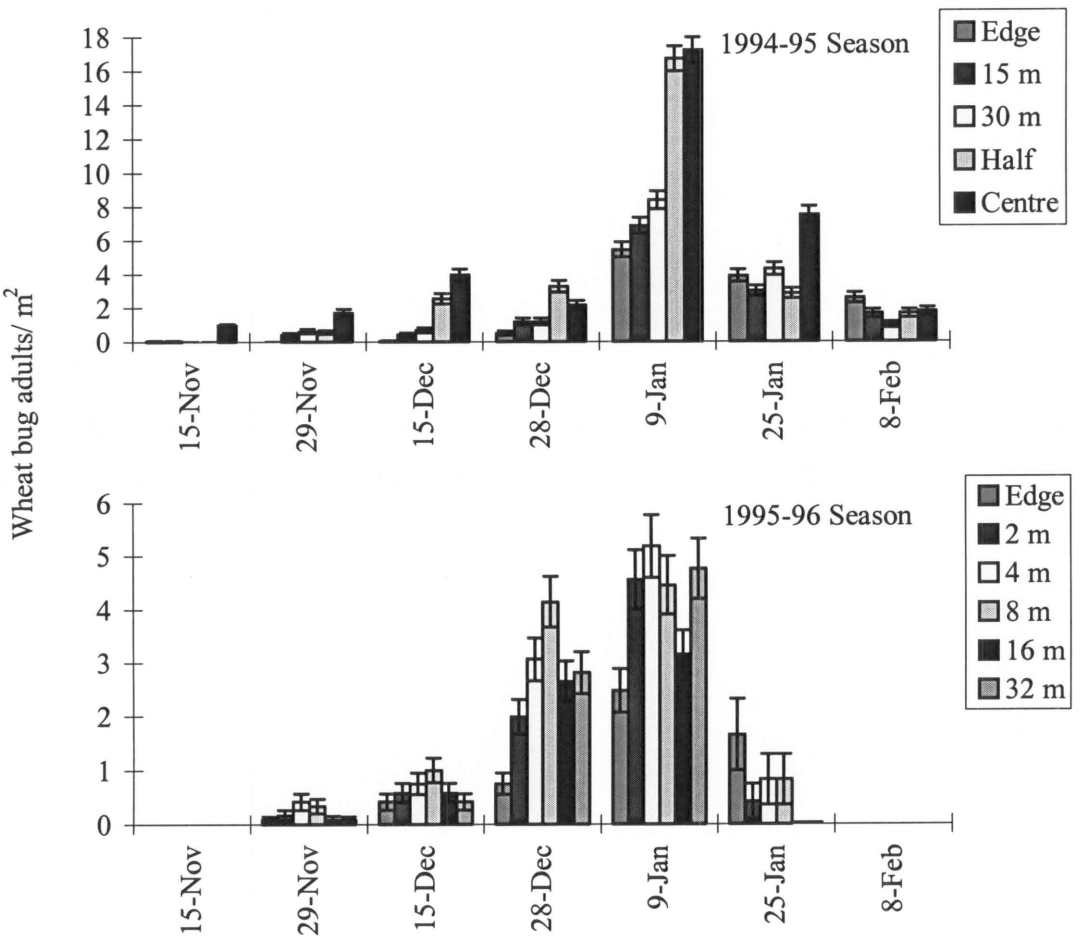

Figure 10. The density of wheat bug adults (± SEM) at different sampling positions in Canterbury white clover seed crops during the 1994-95 and 1995-96 seasons.

White Clover Seed Yields

Overall, the seed yields from each field were not significantly ($P > 0.05$) different between the different growing regions during both seasons. However, the pooled seed yields from different sampling positions were significantly ($P < 0.01$ and $P < 0.05$) different during the 1994-95 and 1995-96 seasons, respectively (Table 6). During 1995-96, these differences ranged from 28.3 ('edge') to 41.6 g/m^2 ('centre') and represented an equivalent seed yield loss of 133 kg/ha. However, the seed

yields ranged between 27 ('edge') and 35.7 g/m^2 (3 m) during 1995-96, which was the equivalent to a 87 kg/ha seed loss (Table 6).

Table 6. Total white clover seed yields (g/m^2) collected from the different sampling positions within each growing region. $LSD_{0.05}$ given for comparisons within sampling positions in each growing region.

	1994-95 Season yields (g/m^2)								
	Ashburt Barrhill	**Coastal Ashburt**	**Darfield**	**Lincoln**	**Methven**	**Sheffield**	**South-bridge**	**Timaru**	**Pooled**
Edge	24.8	42.7	27.6	46.1	15.9	20.2	27.9	25.3	28.3
15 m	36.0	35.9	33.6	63.4	25.7	25.9	41.7	32.1	35.8
30 m	38.7	46.0	28.5	67.7	36.5	30.5	25.8	37.9	37.7
Quarter	34.7	34.4	31.2	47.8	43.4	28.2	36.4	43.1	36.7
Centre	45.8	48.5	32.9	65.1	40.0	23.3	39.1	47.6	41.6
$LSD_{0.05}$	17.2	17.2	17.2	21.0	17.2	17.2	17.2	21.0	6.3
Mean	36.0	41.5	30.8	58.0	32.3	25.8	34.2	37.2	36.0

	1995-96 Season yields (g/m^2)					
	Barrhill	**Coastal Ashburt**	**Darfield**	**Methven**	**Timaru**	**Pooled**
Edge	41.0	20.7	28.7	28.7	16.1	27.0
2 m	45.5	38.5	34.6	39.1	20.7	35.7
4 m	48.8	36.2	32.4	36.2	16.4	34.0
8 m	44.1	41.6	29.6	37.3	12.5	33.1
16 m	42.3	41.2	34.8	31.9	11.6	32.4
32 m	46.4	39.4	21.1	24.7	17.3	29.8
$LSD_{0.05}$	20.5	20.5	20.5	20.5	20.5	5.6
Mean	44.7	36.3	30.2	33.0	15.8	32.0

Weather and Crop Variables

Weather variables (e.g., rainfall, ground and air temperature) for each of the growing regions were not readily available, for each season. However, air temperatures and, to a lesser extent, rainfall data collected from the nearest meteorological stations (Figure 4) were seasonally similar between growing regions. Another indication of seasonal variations between the growing regions was shown by the differing harvest dates (Tables 3 and 4). During the 1994-95, white clover crops in coastal Ashburton, Methven, Sheffield, Southbridge and Timaru were all harvested later, due to cool winds along the coast (coastal Ashburton and Southbridge), higher altitude (Methven and Sheffield, refer Figure 3) or higher latitude (Timaru). The soil profile at Darfield is, overall, of a shallow soil over free-draining shingle and stones compared with deeper soils in the other cropping

regions (Appendix A). This meant that crops grown in Darfield are prone to drying out and were the first to be harvested in Canterbury. During 1995-96, Darfield experienced a drought following the first flowering[7]. However, the first inflorescences received full pollination and provisioning resulting in harvestable seed yields that were not significantly ($P > 0.05$) different from the previous season (Table 6). At the other extreme, Timaru experienced a wet season in 1995-96, which resulted in greater vegetative growth and lower seed yields. Oldfield's crop (Timaru) was not harvested due to the excessive vegetative growth, which caused most of the developed inflorescences to fall to the ground and the seeds to sprout. While the weather and soil variables have a large impact on white clover growth, other crop management variables like irrigation application, time of crop sowing, time of crop closing (removing grazing stock), and fertiliser application can also influence crop development and time of harvest.

Questionnaire

Of the 15 growers surveyed (Appendix B), eight returned completed forms. The total for each question is given on the Appendix sheet. Low numbers correspond to the high level of importance the growers placed on each question.

When asked what information the growers used to make their insect pest management decisions, the majority replied that farm advisers and grain agents were the main source of information followed by chemical manuals and previous experience. When asked what information they felt was lacking and would make their decision-making easier, they replied that they wanted more information on economic benefits of spray applications, a better understanding of the pests and their impacts on white clover seed losses, and quantitative information on pest thresholds and the timing of insecticide applications based on thresholds or crop developmental stages.

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[7] First flowering refers to the first chronologically formed inflorescence along the stolon (refer to Figure 1, Chapter 1).

DISCUSSION

Several growing regions had similar growth and weather patterns during 1994-95, therefore, to reduce the time spent in the field, the number of growing regions was decreased from eight to five in 1995-96. The Lincoln, Sheffield, and Southbridge regions were not sampled during 1995-96.

The aim of the field surveys was to include as much variability from the different growing regions as possible, while sampling from fixed distances into the crops. The fixed distances were modified in 1995-96 following analysis of the distribution data from the previous season. The sampling distances were reduced primarily to obtain more accurate information about PM invasion into the white clover crops.

Monitoring arthropod densities during the two seasons confirmed the preliminary findings of 1993-94 (Schroeder 1995) that BGLA and PM were the most abundant species within white clover seed crops grown in Canterbury. The occurrence of these two species coincided with inflorescence development and resultant feeding injury at this crop growth stage could result in a decrease in inflorescence density and resultant seed yields. Meadow spittlebug was the only other hemipteran pest found during inflorescence development, but in low densities. Experiments conducted by Pearson (1991), using caged meadow spittlebug, showed that it had no significant effect on white clover yield components (inflorescence density, number of florets per inflorescence, and numbers of seed per floret). The impact of wheat bugs during the seed fill stage is not known.

Potato mirids

Potato mirid was first recorded by Cumber (1953) in pasture and fodder crops in the North Island. In a study of lucerne crops, Farrell and Stufkens (unpublished) found that PM nymphs and adults reached their respective peaks during November and January. Only adults were collected during mid January by Macfarlane *et al.* (1981). These results are similar to those collected from white clover crops during this study, where the nymphs reached maximum density in late November followed by maximum adult densities in mid December (1994-95 season) and early January (1995-96 season). The mean peak density of PM nymphs ($40/m^2$) collected in the edge of white clover crops during the 1993-94 season (Schroeder 1995), was also similar to those collected at the edge during 1994-95 in this study. Lower nymphal densities collected at the edge during 1995-96 could be due to a variety of factors including low oviposition in the previous season, high egg mortality

due to weather factors, or high mortality of early instars due to cooler weather. Purcell and Welter (1990) found that the lowest developmental threshold for PM was 6.39°C and that development from newly emerged nymph to the fourth instar required a mean of 142 degree-days. The cooler weather experienced during the 1995-96 season may have also delayed PM development resulting in the later peak of adults. A significant increase in pistachio yield was obtained by Purcell and Welter (1990) when controls were applied to weedy verges around the crop before the emerence of PM adults. This was achieved by cultivating the verges early in the season to reduce egg densities and thereafter to control invading nymphs.

Potato mirid was found in all the growing regions sampled. Overall, it was observed that each area had the potential for the development of large PM populations. However, on a field basis, reduction of the sampling distance to 32 m into the crop during 1995-96 showed that PM nymphs and adults were largely restricted to the edge and up to 4 m into the crop. Such restriction of the sampling area or sampling universe are advisable if initial studies show that the target species occurs predominantly in one portion of the habitat or crop area (Buntin 1994). While PM nymphs are able to walk relatively long distances to a suitable host (e.g., 12 m, as shown in the cage experiment Chapter 5), there are probably two reasons for the stratification observed in this study. First, at the time of PM nymph invasion white clover is growing rapidly and producing large numbers of inflorescences (Chapter 3), which act as a readily available food source reducing the need to go further into the crop. Second, adults are more likely to find mates in an area of high adult density and, therefore, aggregate in the same crop margins to mate and later fly to suitable oviposition sites.

Both PM nymphs and adults were observed to feed solely on the developing inflorescences. In an Australian study, Hori and Miles (1993) showed that the development of green mirid (*Creontiades dilutus* Stål) was dependent on the availability of lucerne flowers and seed pods. When green mirid nymphs were provided with foliage only, they were unable to develop to maturity compared with 65% that completed their development when provided with flowers. This suggests that specific proteins found in reproductive plant tissues are required for green mirid to complete development. Potato mirid preference for reproductive plant parts may be for the same reason, although this has not been tested. Potato mirids were also observed to feed on several weed species that flower during the same period. These included yarrow (*Achillea millefolium* L.) and nodding thistle

(*Carduus nutans* L.). However, they did not occur in high densities within white clover crops used in this study.

The high densities of PM collected in the crop edge coincided with observed inflorescence damage (Plates 12 and 13, Chapter 5) and the degree of damage appeared to depend on the plant developmental stage. Pearson (1991) also observed this with Australian crop mirid feeding on white clover. Total inflorescence senescence occurred when Australian crop mirids were caged on young inflorescences with a petiole length < 2 cm. A similar study of the impact of known PM nymphal intensities on white clover production is presented in Chapter 5.

Bluegreen lucerne aphid

Cox and Dale (1977) first reported BGLA in New Zealand in 1975, five months after it had first been discovered in Australia (Cameron and Walker 1989). The seasonal abundances of BGLA in white clover crops during this study and in a previous study (Schroeder 1995) were similar to those found in lucerne (Rohitha *et al.* 1985; Rohitha and Penman 1986b). The other potential species of aphids found in white clover crops are pea aphid, *Acyrthosiphon pisum* (Harris), and two spotted alfalfa aphid, *Theriophis trifolii* Monell form *maculata* (Cameron and Walker 1989); however, these species are more common during warmer summer periods (Rohitha *et al.* 1985).

The distribution of BGLA was more uniform throughout the crop compared with PM. The distribution of BGLA in the crops is likely to be a function of its dispersal flights into crops. Both spring and autumn flight peaks occur, with the spring peak being the larger (Trought and Kain 1977; Rohitha and Penman 1986a). In Canterbury lucerne crops, the spring flight peaked in late November (Rohitha and Penman 1986a). In both seasons, the densities of BGLA declined rapidly after mid December. This rapid decrease in densities was also observed by Rohitha *et al.* (1985) in a lucerne crop. Rohitha and Penman (1986a) suggested that this rapid decrease did not correspond to an increase in alate flights. Nielson and Barnes (1961) found that a similar collapse in spotted alfalfa aphid in Arizona was largely due to the fungus pathogen *Entomophthora* spp., which are favoured by cool humid conditions. Natural enemies (e.g., Tasmanian lacewing, *Micromus tasmaniae* and elevenspotted ladybird, *Coccinella undecimpunctata*) may also play a role in decreasing BGLA densities and this will be evaluated further in Chapter 6.

Results from the field surveys over two seasons showed that BGLA numbers, like PM numbers, during the season are dependent on several conditions of which winter survival and suitable weather for development are necessary. Rohitha and Penman (1986b) studied the impact of weather variables on flight thresholds and found that multiple regression analysis failed to reveal any clear relationship between the weather conditions and BGLA flight. In this study, the Barrhill growing region recorded the highest (1995-96) and lowest (1994-95) BGLA densities over the two seasons. An apparent relationship between crop density and BGLA numbers was observed and denser crops had higher BGLA numbers. A denser crop also represents a higher food resource and creates a moist microclimate favouring BGLA population increases. However, moist cool conditions are also ideal conditions for *Entomophthora* spp. fungi spread (Nielson and Barnes (1961)).

Trought (1977) found that an infestation of four aphids/inflorescence had no significant impact on white clover (cv. Huia) seed yields, but with 16 or more aphids per inflorescence a 20% seed yield loss could occur. The specific feeding impact of BGLA on white clover was not studied by Trought, nor did he consider the contributions made by other insect pests present (e.g., clover casebearer moths and PM) to the overall seed yield losses. However, Trought and Batey (1980) developed a spray action threshold of two BGLA per inflorescence. This threshold was based on the potential for BGLA densities to build up rapidly within a short period. However, the specific impact of BGLA feeding on developing white clover inflorescences has not been determined in this study.

Wheat bugs

Wheat bug has a large host range that includes cereals, peas, linseed, lucerne, weeds and several vegetable crops (Burnett 1984), but has not been recorded as a serious pest in white clover seed crops. The high densities that were collected in Wilson's crop during 1994-95 could, therefore, have been the result of a residual population from the previous seasons wheat crop. The highest densities collected in the white clover crops in this study occurred after the main flowering and during the seed filling period. This corresponds to previous observations that wheat bugs are usually associated with the hotter summer months (late-January and February) (Burnett 1984) and invasion flights into crops during this period are common (M. Stufkens pers. comm.). High wheat bug numbers were associated with low white clover plant density and an open crop structure where

higher temperatures can occur. However, such space in crops implies poor crop management and does not ensure the maximum use of land area for reproductive returns. Burnett (1984) recommended insecticidal control for high wheat bug numbers, however, re-invasion from other crops may occur.

The main studies on wheat bug feeding injury and resultant effect on seed quality have centred around wheat where it has been shown that injected salivary enzymes remain within the wheat kernel and destroy the gluten structure of dough and cause poor quality bread (Every *et al.* 1992). To date, there have been no specific studies to determine the impact of wheat bug feeding injury on white clover seed production, but seed quality (1000 seed weight) and germination are the two most likely aspects to be affected.

White Clover Seed Yields and Growing Conditions

The differences in seed yields between the different growing regions was mainly due to different growing practices (Tables 3 and 4) and crop management based on soil types (Appendix A), availability of irrigation, and the overall impact of the weather during the season. Each growing region, in a favourable year, can produce white clover seed yields in excess of 600 kg/ha. In areas like Southbridge and Barrhill, it is common for seed yields to be as high as 8-900 kg/ha. These two regions have deep soils that become drier, thus placing water stress on the clover plants in mid-late December. In general, limiting the soil moisture reduces leaf size which, in turn, results in more leaf-associated inflorescences with lower floret numbers and higher resultant seed yields per unit area (Clifford 1985a) (refer to section 'plant stresses' in Chapter 1). Darfield had shortened seasons due to the lighter soils and drought conditions, while Timaru had a later, cooler, and wetter growing environment and represents the southern-most growing white clover region. Latitudinal differences can be further modified by changes in altitude, which in particular can have a frosting effect on flowering ability in extreme conditions. For example, 300 m above sea level is considered to be the upper altitudinal limit for commercial white clover seed production due to the increased frequency of frost damage beyond this level (refer Figure 3).

White clover seed yields (Table 6) were consistently lower at the crop edge where the highest number of PM were collected suggesting that it may influence seed yield. However, the growing conditions at the edge of the crop may be quite different from those further into the crop. Weed

(including volunteer white clover plants) densities nearer the edges were higher and could be used by the insect pests as host plants before white clover inflorescence development. This would result in movement from a high pest density on to the white clover crop plants at inflorescence development. In the case of PM, the movement and development of the different instars into the crop can be studied (in Chapter 3). The signs of rabbit (*Oryctolagus cuniculus* L.) feeding on inflorescences along the edge was also observed in some fields.

The purpose of this study was to determine the spatial and temporal distribution of insect pests over a wide sampling area. Southwood (1978) termed this approach to arthropod sampling as extensive, where the sampling activity is limited but covers a range of habitats and a large geographic area. With the identification of the key insect pests (PM and BGLA) a more intensive sampling programme is required to determine the pest population ecology for the development of an IPM programme.

This study has examined the arthropod fauna associated with white clover seed crops grown in the province of Canterbury. The study was designed to include as much variety from the different growing regions as possible, so that the key insect pests and arthropod predators could be identified for a range of different growing and crop management practices. The following experiment (Chapter 3) was designed to focus the sampling effort in one field. Data were also collected on plant growth development in an attempt to understand the interactions between the crop and arthropod phenologies.

CHAPTER THREE

INTENSIVE FIELD MONITORING

INTRODUCTION

Despite many advances in sampling methodology made recently, adequate sampling programmes for IPM are lacking for many important pests in cropping systems (Nyrop & Binns 1991). Because sampling information is used in IPM to make decisions about therapeutic or curative actions such as use of insecticides to prevent pests from causing significant damage, the absence of inexpensive, user-friendly sampling protocols may well be the greatest impediment of IPM practice in agriculture today (Pedigo 1994). Clearly, reliable practical sampling programmes are essential for the effective utilisation of control tactics in IPM systems (Buntin 1994).

The prime objective of the research in the previous chapter was to identify the key insect pests associated with white clover seed production in the Canterbury growing region. The approach used was to broadly sample one transect per field. This was done to include a variety of habitats over a wide geographic area, defined by Southwood (1978) as an extensive sampling programme. However, an extensive sampling programme involves a great deal of variability associated with the collected data. The next step in the development of a sampling programme for IPM is to carry out intensive sampling to determine the sample sizes required to increase the precision of the sample estimates for reliable decision making.

The only intensive sampling programmes for white clover seed crops are for the two clover casebearer moth species (*Coleophora* spp.) (Pearson 1982) and for bluegreen lucerne aphid (BGLA, *Acyrthosiphon kondoi*) (Trought and Batey 1980). A preliminary sampling study of aphids in lucerne crops was developed by Rohitha (1979) who found that the level of precision of mean aphid density was dependent on the height of the crop. A suction sample unit of 800 cm^2 gave the best absolute estimates when the crop was short in June. However, when the crop was higher than 65 cm, single stems were the most appropriate sampling unit with 22 stems giving a standard error within 10% of the mean. Rohitha (1979) also used a suction sampler (an earlier version of a D-Vac) which required 55 samples of 300 cm^2 to give an estimate of the mean aphid

density with an error of ± 10%. The following study was conducted using a suction sampler similar to that described by Arnold (1994), who established that it was more effective than a D-Vac sampler.

Clearly, good sampling programmes used with appropriate action thresholds can significantly reduce the cost of control. An example of an effective sampling programme is that developed by Durham (1982) for South Australian lucerne crops. Durham (1982) showed that costs could be reduced from $31/ha to $6/ha following the implementation of a pest management programme with established action thresholds. The following field experiment was designed to study the spatial and temporal distribution of insect pests within one white clover field with different border orientations and neighbouring crops. In addition, relationships between the two key pests (potato mirid nymphs (PM) and bluegreen lucerne aphid (BGLA), inflorescence number, percent inflorescence damage and resultant seed yields were investigated. The main objective was to provide information for the development of a suitable insect pest sampling programme and possible action thresholds for white clover seed crops. Some of the practical aspects of current crop management practices will also be discussed.

MATERIALS AND METHOD

The intensive field sampling study and yield loss assessment experiment were conducted during the 1995-96 season in a non-irrigated, 7.5 ha, first-harvest Grasslands Huia white clover seed crop at Tai Tapu (8 km east of Lincoln). A Huia crop was chosen because first-harvest Huia crops represent approximately 80% of the total white clover grown for seed in Canterbury and are the crops most likely to be used in future studies. The field was situated on a deep Templeton silt loam among a variety of different neighbouring crops (Figure 11). Each of the crop boundaries contained weedy verges (e.g., white clover; gorse, *Ulex europaeus* L.; fathen, *Chenopodium album* L.; yarrow, *Achillea millefolium*; and grasses Graminae spp.), which could serve as potential refuge sites for field invasion by resident arthropods.

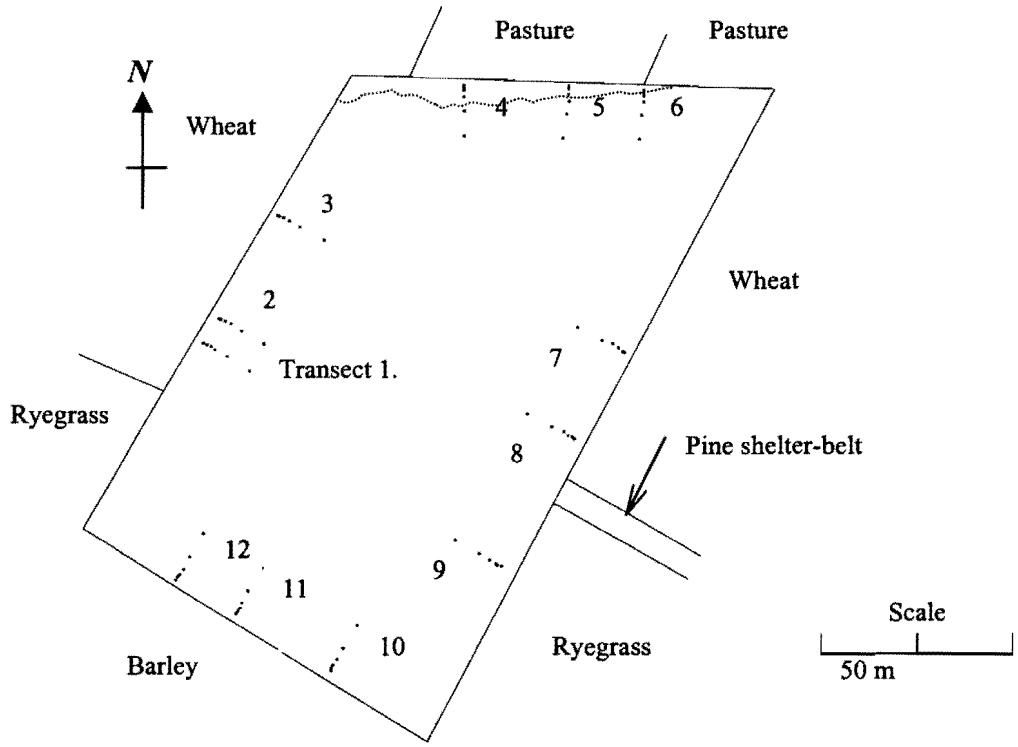


Figure 11. GPS generated field plan showing location of transects and neighbouring crop types. The plant densities around transects 4, 5, and 6 were low and patchy in distribution and are denoted by the broken line, south of which there was a relatively uniform white clover seed crop.

Three transects per boundary edge (Figure 11) were marked out in mid November. Transect selection was based on good clover plant density and were not randomly located. Each transect had six sampling positions (edge, 2, 4, 8, 16, and 32 m in to the crop) (Plate 5) which were sampled bi-weekly during the white clover flowering (20 November, 5 and 19 December, and 3 January) for arthropods using a suction sampler. The sampler consisted of a two-stroke Stihl (BG72) motor mounted on a collection container covering a 201 cm^2 suction area, similar to the design described by Arnold (1994). The sample unit chosen was 40, three-second suctions taken at each sampling position along each transect (the 40 suctions comprised a sample unit of 0.804 m^2). The arthropod samples were collected in four plastic pottles containing ten suctions each and stored in a freezer (-20^{0}C) for later species identification and counting. In most cases the four pottles for each sampling position were grouped together for species identification and counting, however, for some transects individual pottle counts (10 suctions) were recorded over the sampling period to compare the precision of a smaller sample unit size (0.2/m^2).

Plate 5. Sampling position markers used during the experiment. Sampling was alternated from left or right of the pegs on alternate sampling days.

For both sample unit sizes, the number of units required to obtain an estimate of insect density within an error of ± 20% (suitable for management decisions) was calculated using the following formula:

$$N \geq \frac{4s^2}{D^2 \bar{x}^2} \qquad (1)$$

where: N = the number of sample units (pottles) required

s^2 = the pooled mean variance

D = the error of estimation

$\bar{x}$ = the pooled mean

(Snedecor and Cochran 1980)

Total inflorescence and damaged inflorescence numbers at each sampling position were recorded inside a 0.5 x 0.5 m quadrat on 22 January, before harvesting. On 30 January the crop was sprayed with glyphosate ('Roundup®', Monsanto N.Z. Ltd.) at 1.5 litres/ha to control couch grass, *Agropyron repens* (L.), to reduce plant growth and to open up the crop for a desiccant herbicide application. All the sampling positions were strip sprayed (0.5 x 5 m) with diquat ('Reglone®', 200g a.i./l, Crop Care N.Z. Ltd.) at 1 ml/l the following day. The desiccant spray was applied to promote drying of the harvested samples before the grower harvested the crop.

Harvest samples (0.45 x 5 m) were taken from each sampling position on 3 February using a rotary lawnmower. All plant material was placed into a paper bag and then put into a drying oven (80^{0}C) for 24 hours before recovering the white clover seed using a belt thresher. The samples were then cleaned and graded using a wind-draft seed dresser and column separator.

Analysis of Results

Data for PM nymphs and adults, and BGLA were analysed by ANOVA using the Poisson error distribution in Genstat® for Windows (© Lawes Agricultural Trust, IACR, Rothamsted, U.K.). ANOVA was used to determine differences in seed yields and to determine the effects of border orientation of the four boundaries, neighbouring crop (barley, pasture, and wheat) and transect position. Linear regressions were used to determine the relationships between PM and BGLA densities and inflorescence damage.

RESULTS

The arthropods collected during the experimental period are summarised in Table 5 (Chapter 2). Results here are given for the two key pest insects (PM and BGLA). Data has been pooled for each position at each sampling date as there were, generally, no significant differences in insect numbers found between transects.

Potato mirid nymphs

When all transects were pooled, the highest PM nymphal numbers were recorded in the edge position (46/m^2 ± 2) on 20 November (Figure 12).

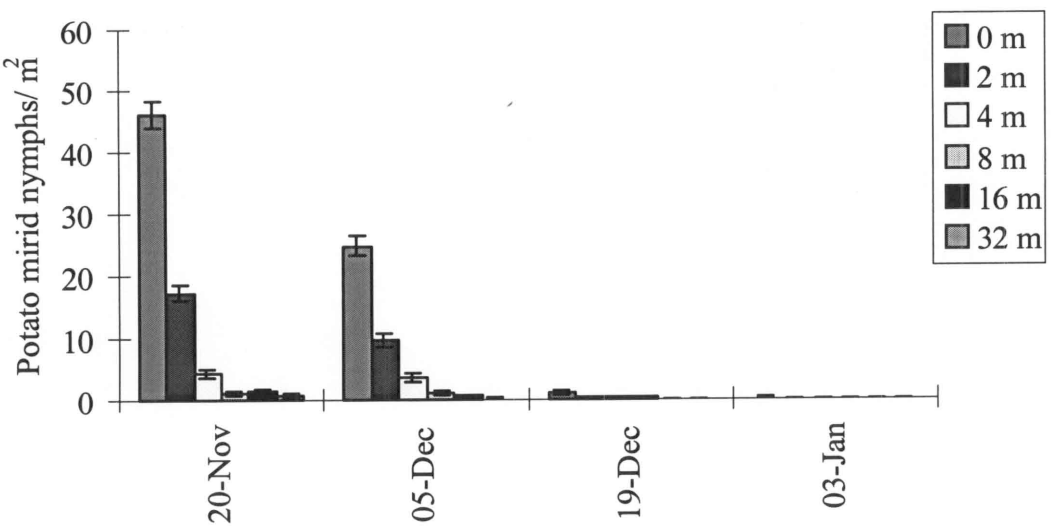


Figure 12. Pooled potato mirid nymphs (± SEM) collected in bi-weekly suction samples at a range of distances into a white clover seed crop situated in Tai Tapu.

Significantly ($P < 0.001$) higher numbers of PM nymphs were consistently collected at the edge position compared with all other sampling positions. Numbers ranged from 46 to 0.7/m^2 on 20 November at the edge and 32 m positions, respectively.

Potato mirid adults

Adult PM numbers peaked four weeks later than PM nymphs on 19 December, but the distribution was similar with significantly ($P < 0.001$) greater numbers collected at the edge (Figure 13). The density of PM adults ranged from 9.2/m^2 at the edge, to 0.2/m^2 at the 32 m position on 19

December. There were no significant (P> 0.05) differences between adult PM densities collected from the different transects, nor were there any significant effects of transect orientation or neighbouring crop type.

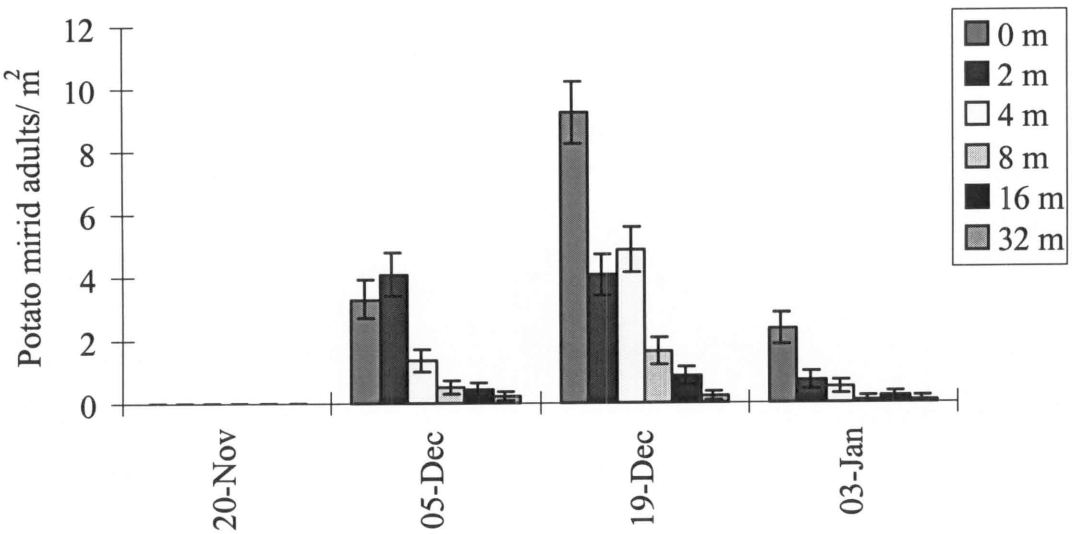


Figure 13. Pooled potato mirid adults (± SEM) collected in bi-weekly suction samples at a range of distances into a white clover seed crop situated in Tai Tapu.

Bluegreen lucerne aphid

Bluegreen lucerne aphid densities ranged from 0 in early January and peaked around 19 December at 1079/m^2 (Figure 14).

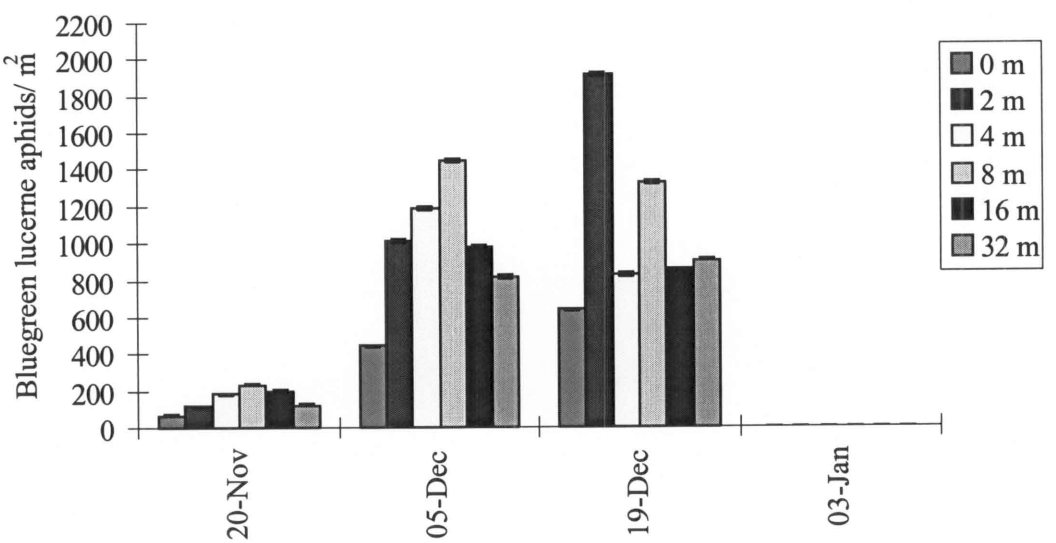


Figure 14. Pooled bluegreen lucerne aphids (± SEM) collected in bi-weekly suction samples at a range of distances into a white clover seed crop situated in Tai Tapu.

No significant (P> 0.05) differences in BGLA densities were found between the different sampling positions, but there was a significant ($LSD_{0.05}$ 514, P< 0.001) difference between transect 1 (2038/m^2) and 4 (58/m^2), which could be due to differences in plant densities between the two areas (refer Figure 11). Border orientation and neighbouring crop type had no significant (P> 0.05) effect on BGLA densities and there was no significant difference between the numbers of insects collected at each sampling position.

Inflorescence Assessment

Overall, there was a significant (P< 0.05) difference in total inflorescence densities between transects recorded before harvest. The lowest inflorescence density was 594/m^2 in transect 4 and the highest density was 1051/m^2 ($LSD_{0.05}$ 271) in transect 12. In general, the lowest mean total inflorescences was recorded in the edge position (701/m^2), which was significantly ($LSD_{0.05}$ 192, P< 0.01) lower than in the 2 m position (966/m^2) (Figure 15a).

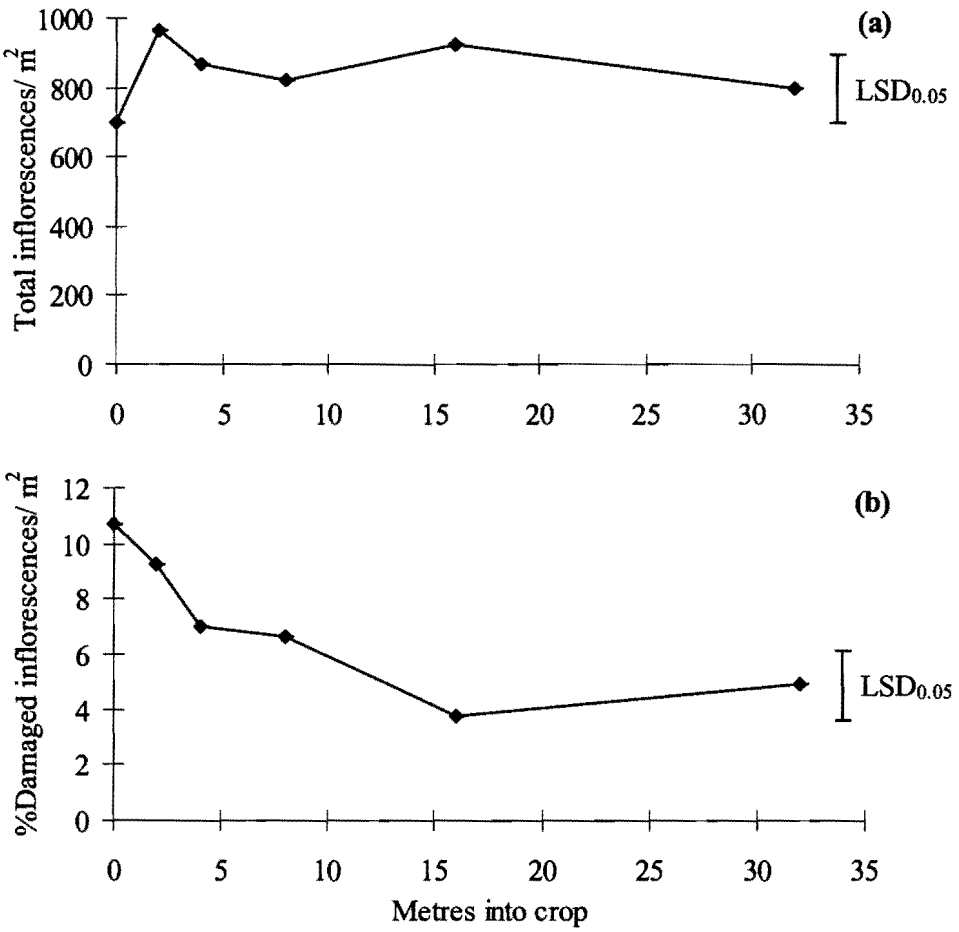


Figure 15. The overall mean numbers of (a) total and (b) proportion of white clover inflorescence damage (%Damaged) recorded from each sampling position before harvest.

There was a significant ($P< 0.001$) difference between the proportion of damaged inflorescences/m^2 at each transect, probably indicating non-uniformity in the crop growth. There was also a significant ($LSD_{0.05}$ 2.5, $P< 0.001$) difference between the percentage of damaged inflorescences and sampling position, with proportionately more damage occurring at the edge (10.7%) and decreasing further into the crop (3.7% at 16 m) (Figure 15b).

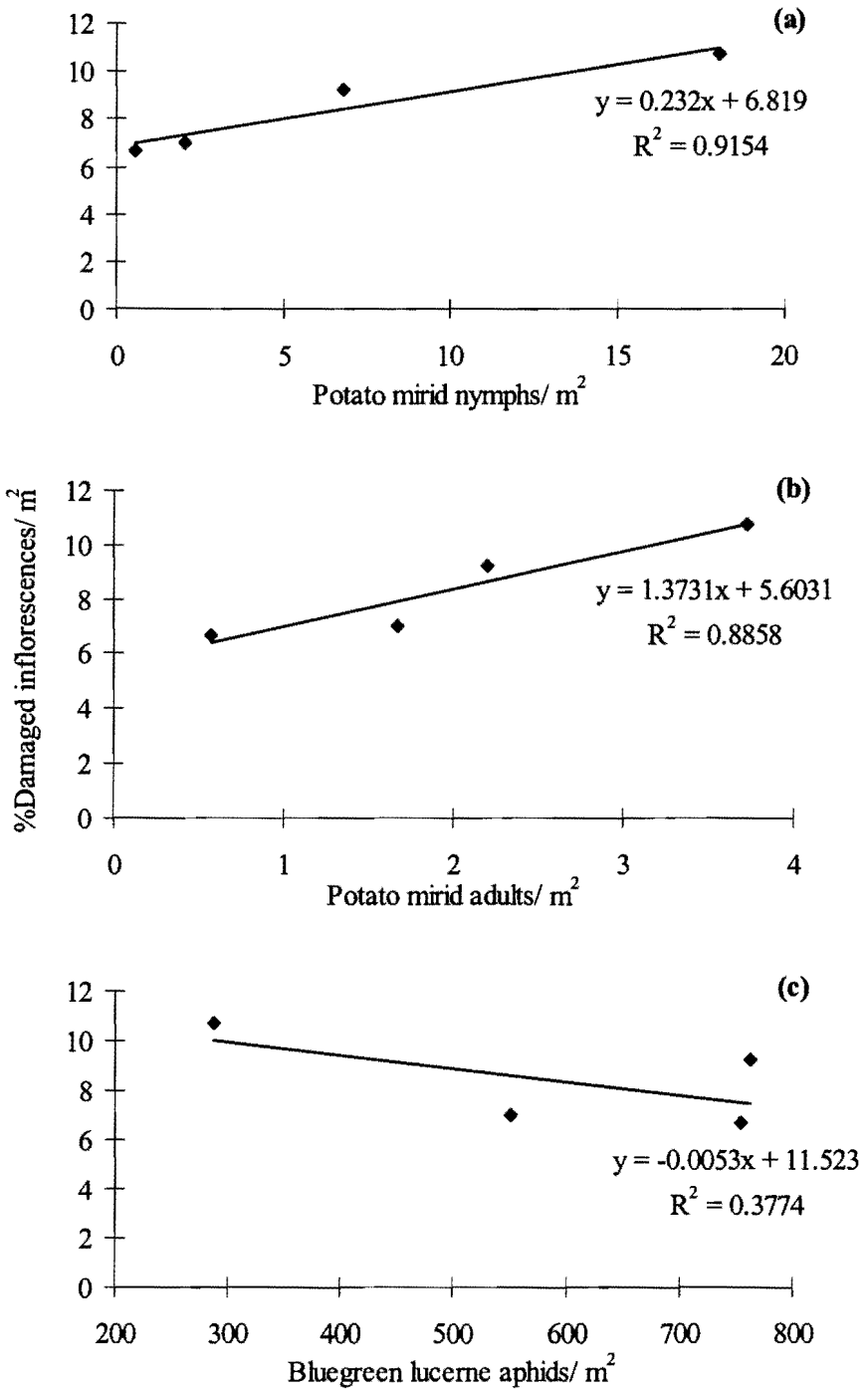


Figure 16. Mean (a) PM nymph, (b) adult and (c) BGLA densities versus the proportion of damaged inflorescences (%Damaged) recorded at the edge, 2, 4, and 8 m positions. Linear regression lines of best fit are given with their respective R^2 values.

When the percentage of damaged inflorescences over the positions from the edge to 8 m were regressed against the density of PM nymphs and adults at the same sampling positions, a significant linear relationship was found (Figure 16a and b). However, the regression between BGLA densities and proportion of damaged inflorescences at the same sampling positions was not significant (Figure 16c).

Harvest Yields

There were significant ($P< 0.05$) differences in first quality and total white clover seed yields between the different sampling positions (Figure 17). Second quality seed yields were not significantly ($P> 0.05$) different. However, second quality seed made up only 2% of the total seed yield. The lowest (60 g/m^2) overall total seed yields were harvested from the edge positions compared with the highest yields (73 g/m^2) from the 4 m position. There was a significant ($LSD_{0.05}$ 10, $P< 0.01$) difference between the mean seed yields harvested from each transect, ranging from 43 g/m^2 in transect 4 to 65 g/m^2 in transect 3.

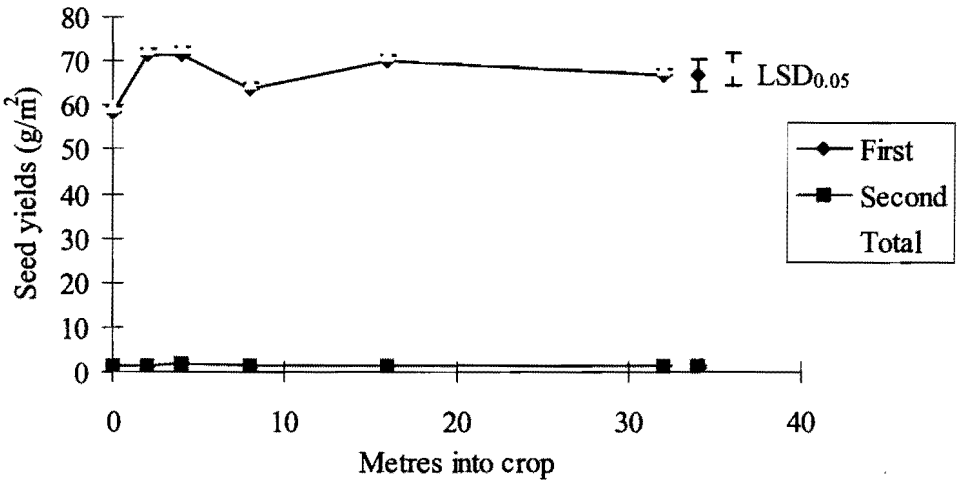


Figure 17. Mean first, second, and total white clover seed yields collected from the harvested samples at each of the sampling positions.

Increasing inflorescence numbers resulted in increasing seed yields, which followed a significant linear relationship (Figure 18).

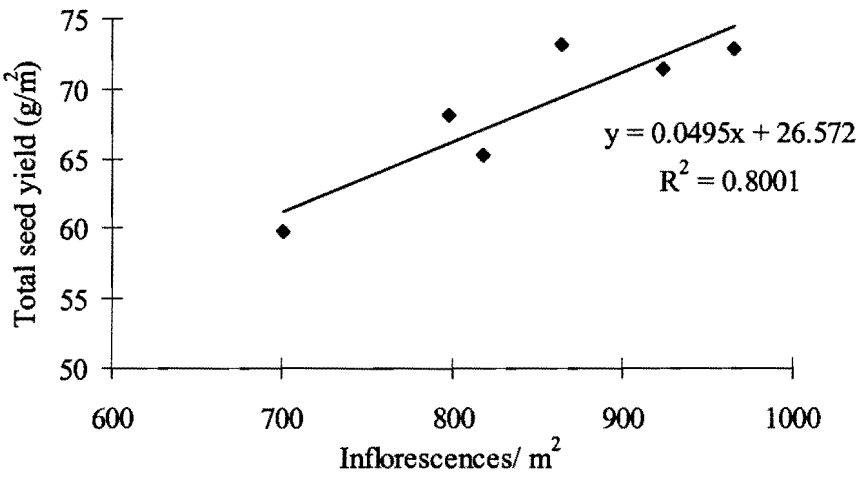


Figure 18. Linear regression analysis of mean inflorescence numbers versus total seed yields collected from each sampling position.

Sampling

The means and variances of the two sample unit sizes (0.8 m^2 and 0.2 m^2) were used to determine the number of sample units (for each respective size) required to estimate the mean density of PM nymphs and BGLA within an error of ± 20%, assuming random sampling. For both insects, the smaller sample unit (0.2 m^2) gave the smallest variance and therefore sample sizes that were considered practical for future monitoring.

Potato mirid nymphs

Table 7 shows that different numbers of sample units are required to get a reliable estimate of the mean density (± 20%) on different sampling dates. The high variance (relative to the mean) associated with the 20 November sampling indicates that the spatial distribution of PM nymphs was clumped. The means and variances for the other dates are similar and, therefore, more likely to follow the Poisson (random) distribution. Larger sample numbers are required for the much lower PM nymphal densities (refer Figure 12) later in the season.

Table 7. The number of sample units (pottles) required to be collected at different sampling dates to obtain a reliable estimate of the mean density of PM nymphs (± 20%). The presented data were collected from the 'edge', 2 m and 4 m positions where PM nymphs were most abundant.

	Sampling Dates		
	20 November	**5 December**	**19 December**
Sample units (pottles)	12	24	36
Pooled mean/pottle	4.9	4.4	0.1
Pooled variance/pottle	13	2.5	0.09
Sample units required	54	13	750

Bluegreen lucerne aphids

The number of sample units required to estimate the mean density (± 20%) of BGLA is lower than those for PM nymphs (Table 8). However, by 3 January the required sample numbers were very high, due to low BGLA densities (Figure 14). The differences in means and variances at each sampling date indicated that BGLA had a clumped dispersion.

Table 8. The number of sample units (pottles) required at different sampling dates to obtain a reliable estimate of the mean density of BGLA (± 20%). The presented data were collected from all sampling positions ('edge' to 32 m).

	Sampling Dates		
	20 November	**5 December**	**20 December**
Number of pottles	24	48	72
Pooled mean/pottle	40	175	195
Pooled variance/pottle	233	5164	14403
Pottles needed	15	17	38

DISCUSSION

Potato mirid nymphs

Potato mirid nymphs and adults were collected in high densities closer to the white clover crop edge confirming previous findings (Chapter 2, Schroeder 1995). For crop monitoring purposes, it would be important to sample the area from the edge to 4 m into the crop where PM densities are higher and where damage is likely to occur. There was a large reduction in PM adult densities around mid December due to dispersal when adult PM was observed throughout the white clover crop and in other nearby crops (e.g., lucerne and lotus). If PM nymphs and adults are economically important pests, specific control could be achieved during the nymphal stage by the application of a suitable insecticide sprayed around the crop verges.

Both PM nymph and adult numbers were unaffected by border orientation or neighbouring crop type as similar numbers were found in each transect. Initially, it was expected that different border types would provide different oviposition opportunities for adults, thus influencing the numbers of nymphs invading the crop from these borders. These results suggest that border type had no influence on PM oviposition sites. However, of the neighbouring crops, only white clover in the north facing pasture is known to be a host for PM. This study showed that PM is highly concentrated at the field edges regardless of the neighbouring crop, suggesting that it is ovipositing in the field margins and moving from there into the crop. Clearly, further investigation to determine where PM oviposits within field margins may lead to control/removal of these sites as a cultural control strategy for its control.

Observations in other studies have shown that PM feeding can result in complete inflorescence senescence or partial inflorescence damage (Plates 12 and 13, Chapter 5). This was confirmed in this study where a significant linear regression between increasing PM adult/nymph densities and increasing percentage of damaged inflorescences was found within the edge to the 4 m crop margin. However, increased PM densities did not consistently result in significant decreases in seed yield. There could be two explanations for this. First, PM nymphs occurred early in the season before main flowering (with smaller numbers of adults thereafter) causing damage to early developing inflorescences. These early inflorescences usually do not get adequate pollination due to low honey bee numbers early in the season. Even if good pollination occurs, an early inflorescence will usually develop to a seed head and fall to the ground where it is out of reach for

harvesting. Later inflorescences that develop after peak PM densities may produce better quality seed to compensate for earlier seed yield losses. Second, inflorescences that have been damaged at an early developmental stage will senesce and will not be accounted for in the pre-harvest count (Plate 4, Chapter 5). Inflorescences that are partially damaged from PM feeding injury at a later developmental stage (Plate 13, Chapter 5) have reduced floret numbers. However, these florets are well provisioned by plant assimilates as for a full inflorescence. The resultant seed from these inflorescences is likely to be larger and have a higher thousand seed weight, which may compensate for seed yield loss from the destroyed florets. This suggestion requires further study to determine differences in inflorescence seed yield components (e.g., florets per inflorescence, seeds per floret) between different PM damaged and undamaged inflorescences.

Despite a lower inflorescence density, high densities of PM, and decreased seed yields at the crop's edge, it is questionable whether PM nymphs or adults were solely responsible. Clover growth within this area can also be strongly influenced by several crop management practices. For example, the irrigation pattern may frequently miss this crop margin causing water stress to plants or, conversely, over-watering can occur from irrigation application or run-off causing plant death from water logging or increased diseases from root rots. Compacting of soil often occurs around field edges due to stock movement and farm appliance tracks around crops, causing poor establishment of white clover plants. Shading from fence lines (e.g., gorse hedges) may decrease the numbers of white clover inflorescences initiated in this area by reducing daylight intensity. This area also represents the highest weed density within the crop from weed intrusion from the margins. If this area is harvested then high costs associated with weed seed dressing may occur and the seed line may be downgraded. The implications of these factors will be evaluated in combination with the other studies and further discussed in Chapter 7.

Bluegreen lucerne aphid

During the 1994-95 and 1995-96 seasons, BGLA populations peaked in late to mid December, respectively (Chapter 2). The highest density recorded in this intensive field study was 1079 BGLA/m^2 in mid December, which coincided with the peak flowering of the crop and where high numbers of BGLA were observed on developing inflorescences and the flower petioles (Plate 4, Chapter 2). It is likely that feeding injury caused by high numbers of BGLA over this period will not have a direct effect on reducing inflorescence numbers, but will have an indirect effect on seed quality per inflorescence as provisioning for the developing seed is siphoned off by the aphids. This is supported by the lack of a relationship between increasing BGLA densities and increasing

inflorescence damage as was found with PM densities. The specific impact of large numbers of BGLA and plant feeding symptoms and resultant seed yields at different plant growth stages will be studied in Chapter 5. Large numbers of BGLA were found throughout the whole crop compared with the edge aggregations of PM nymphs and adults. It was observed that higher BGLA densities corresponded with higher plant growth or denser crop coverage during the current and previous studies. The higher density of plants represented a larger food source that could support these large numbers.

Crop Sampling Programme

Analysis of the suction samples clearly indicated that a smaller sample unit size (10 suctions, 0.2 m^2) compared with 40 suctions (0.8 m^2) gave greater precision for a smaller sample size. For PM nymphs, the analysis was confined to data collected from the edge to 4 m into the crop where both the extensive and intensive sampling programmes over several seasons clearly indicated both PM nymphs and adults were stratified. The aim was to establish a practical sample size to give estimates of insect density with a realistic level of precision for monitoring purposes and future study. The results suggest it is reasonable to expect that sampling within a stratum for PM would give a reliable estimate of the mean density for that stratum which, in turn, can be used to determine whether an action threshold has been reached (or exceeded) for control decision making.

The sample design for both insects carried out in this study was not a simple random sample, and could be called systematic. In addition, the transects were not randomly positioned within the crop, but selected for uniform plant density so that meaningful data on yield losses in response to insect feeding damage could be collected and studied. Such a design may introduce considerable bias in the sample estimates of insect density. It is suggested that for future monitoring studies that the design be fully randomised (within the 4 m stratum for PM nymphs and throughout the field for BGLA). In addition, while sampling for BGLA, sample units could be checked for possible high densities of PM moving beyond the 4 m stratum into the crop in some seasons. Furthermore, equation (1) used for estimating the required sample size may not be appropriate for BGLA as they show a contagious spatial distribution (variance much higher than the mean) (Table 8). If the distribution is contagious the optimal sample size may be better calculated using the negative binomial distribution described by Southwood (1978).

If PM and BGLA are of economic importance, then tactics for their control need to be studied. Two studies were conducted to address different control tactics and are presented in Chapters 4

(insecticide experiment) and 6 (natural enemy-pest species synchrony experiment). Wightman and Whitford (1982) did the most recent insecticide efficacy experiments conducted in white clover. Most insecticides used in their experiments are no longer commercially available or are toxic to honey bees. Since those studies, two pyrethroid insecticides have come on the market and show promising results for insect pest control in white clover. Experiments in Chapter 4 will evaluate these chemicals along with pirimicarb for use in white clover seed crops.

CHAPTER FOUR

EVALUATION OF THE TIMING AND PLACEMENT OF INSECTICIDE APPLICATION IN WHITE CLOVER SEED CROPS

INTRODUCTION

Schroeder & Clifford (1996) found potato mirid (PM, *Calocoris norvegicus*) and bluegreen lucerne aphid (BGLA, *Acyrthosiphon kondoi*) were the most abundant insect pests collected during the 1994-95 growing season in 24 Canterbury white clover (*Trifolium repens*) seed crops. Both species occurred early in the growing season (mid November to late December) when maximum plant stolon growth and flower development were taking place. The highest densities of potato mirid nymphs occurred in the crop edge at 40/m^2, while BGLA reached a maximum of 800/m^2 within fields. Potato mirid nymphs at densities of 34-48/m^2 result in reductions of up to 148 kg/ha loss in white clover seed yield, corresponding to a loss of $592/ha when seed is valued at $4/kg (Schroeder 1995). BGLA has been associated with stunting and deformation of lucerne plants and significant yield losses (Summers *et al.* 1984) and Trought (1977) predicted 20% seed yield loss could occur in white clover crops with infestations above 16 aphids per inflorescence.

Schroeder *et al.* (1996) found that lambda-cyhalothrin (Karate®, 50 g/litre EC, Crop Care Holdings N.Z. Ltd.) applied at two rates (5 and 10 g a.i./ha) significantly reduced nymph and adult potato mirid and aphid (*Acyrthosiphon* spp.) densities in white clover grown in field cages for up to 12 and 20 days, respectively. Field application of lambda-cyhalothrin reduced aphid densities for up to 7 days after treatment (DAT), but had no effect on potato mirid. This was due to the later application (mid-December compared with late-November to early December) of the insecticide and natural decline in densities of both insect species in the field (Schroeder *et al.* 1996). Of the common natural enemies described by Schroeder and Clifford (1996), only adult ladybirds (*Coccinella undecimpunctata*) were adversely affected by the lambda-cyhalothrin applications (Schroeder *et al.* 1996). Rotrekl (1994) also found that 6.25 g/ha lambda-cyhalothrin was particularly injurious to coccinellids. The impact of insecticides on ladybirds, Tasmanian lacewing

(*Micromus tasmaniae*) and harvestman (*Phalangium opilio*) on BGLA populations in the field is not known as most toxicological studies have concentrated on laboratory experiments. Schroeder and Clifford (1996), however, found that the presence of these predators did not prevent aphid densities reaching up to 4290/m^2 in white clover crops during mid December. Higher predator numbers appeared to occur after aphid numbers had peaked, consistent with predator lag. An earlier application of lambda-cyhalothrin may have prevented aphid densities reaching a high level and allowed predators to suppress populations at a lower level.

Schroeder and Chapman (1995) found that a fluvalinate (Mavrik Aquaflow®, 240 g/l E.C., Yates N.Z. Ltd.) applied just before peak flowering significantly reduced BGLA, and adult Tasmanian lacewing numbers over time. The insecticide was applied on 13 December to coincide with farmers' usual timing. The effect on potato mirids was not investigated as the treated plots did not include the field margins where they occurred in high densities.

Some farmers still apply insecticide for the control of clover casebearer moth (*Coleophora* spp.) in early December, even though these species are successfully controlled by two introduced parasitoids (*Bracon variegator* and *Chrysonotyia trifolii*). However, most farmers apply insecticides to control BGLA because they are visually and numerically more abundant and occur throughout the whole crop. From a practical perspective, farmers want to know: 1) which insect pests are causing economic damage, 2) what do they look like, 3) when do they apply insecticide if required and 4) which is the most effective insecticide?

At present, there are no field tested or scientifically robust recommendations for control of white clover seed pests for the range of currently available insecticides. The most recent field testing of insecticides for use in white clover crops was conducted by Wightman and Whitford (1982). Of those chemicals, only endosulfan (which is toxic to honey bees) and pirimicarb are still commercially available. Since then, the two pyrethroids, fluvalinate and lambda-cyhalothrin, have been added, but they have not been compared in the same field experiment. Both pyrethroids are known to be non-toxic to honey bees and lambda-cyhalothrin is also known to have a repellancy and or antifeedant effect on insects (Blair 1991), which probably also applies to fluvalinate. Pirimicarb (Pirimor®, 500 g/kg DG, Crop Care Holdings N.Z. Ltd.) was shown by Wightman and Whitford (1982) to be selective against aphids, but not mirids or predatory arthropods. Pirimicarb and fluvalinate are registered for use on white clover crops, while lambda-cyhalothrin has only recently (March 1998) been registered.

A comparison of white clover seed crop and insect pest phenologies shows that a critical period for insect feeding injury occurs during inflorescence development up until late flowering (early/mid November to mid/late December), depending on the cultivar flowering type and seasonal variations (Schroeder and Clifford 1996). Pyrethroid insecticides could be applied either as a curative control based on action thresholds or as a prophylactic control exploiting their residual repellency and/or antifeedant effects to provide control over the critical inflorescence developmental stages.

The main objective of this experiment was to determine the influence of timing and placement of two pyrethroid insecticides and pirimicarb for the management of insect pests in Canterbury white clover seed crops.

MATERIALS AND METHODS

Field Sites and Crop Agronomy

Four white clover (cv. Grasslands Huia) fields were used in the experiment (Table 9). Growers names will be used when referring to the specific crops hereafter. Crops were selected in two areas: Tai Tapu, 8 km east and, Leeston, 25 km south of Lincoln. Both areas were infested by insect pests in previous seasons (Schroeder 1995; and 1994-95 survey season).

The type of border varied between fields from gorse hedges at the Lowery and Heslop farms, to farm tracks at the Macartney and Ryan farms (Table 9).

Table 9. The white clover seed crops and the respective management practices used for the insecticide experiment.

Site	Location	Cultivar	Sowing practice	Border orientation*	Irrigated
Macartney	Tai Tapu	1st year Huia	undersown ryegrass	east, south, and west	Yes
Ryan	Tai Tapu	1st year Huia	undersown wheat	south and west	Yes
Lowery	Leeston	1st year Huia	Autumn-sown rows	north and south	Yes
Heslop	Leeston	1st year Huia	Autumn-sown rows	east	Yes

* Due to the length of field edge required for the experimental plots more than one border was commonly used. Border orientation refers to the direction the border was facing.

Experimental Design

The experiment comprised four treatments applied at four different times. The treatments were:

1. lambda-cyhalothrin (10 g a.i./ha);
2. fluvalinate (36 g a.i./ha);
3. pirimicarb (125 g a.i./ha);
4. control (no insecticide).

All treatments were applied with the equivalent of 50 ml 100% non-ionic surfactant ('Superstick', Yates N.Z. Ltd.) in 200 l water/ha. They were applied with a gas-pressurised knapsack sprayer at a nozzle pressure of 200 kPa. The boom consisted of four XR Teejet® 11002VB nozzles spaced to give a 2 m spray swath. Three passes with the sprayer were necessary to cover the 10 m x 6 m-wide plots. The plots were sited along the edge of the crops to determine the effect of treatments on arthropod movement from the crop verge into the crop.

Each treatment was applied once at three different times and as a combination of two timings:

1. first inflorescence development ('First application');
2. second inflorescence development ('Second application');
3. full flowering ('Third application');
4. combination of treatments 1 and 3 ('Double application').

The actual dates of application for each field are given in Table 10.

Table 10. Treatment application dates for each field according to crop development.

	Field			
Application	Macartney	Ryan	Heslop	Lowery
First	21 Nov	28 Nov	2 Dec	22 Nov
Second	2 Dec	10 Dec	18 Dec	2 Dec
Third	18 Dec	24 Dec	24 Dec	18 Dec
Double	21 Nov & 18 Dec	28 Nov & 24 Dec	2 Dec & 24 Dec	22 Nov &18 Dec

Each field represented a replicate in which the 16 treatment plots were arranged around the edges. The plots were grouped for each application time and the four treatments randomly assigned within each group.

Arthropod Assessment

Insect samples were collected using a suction sampler. The sampler consisted of a two-stroke Stihl (BG72) motor mounted on a collection container (similar to that described by Arnold 1994) and covered a suction area of 0.2 m^2. Forty separate suction samples were taken at the crop edge, 2, and 4 m into the crop in each treated area within the plot and another sample outside the treated area at 8 m from the edge. Wooden pegs with markers (Plate 5, chapter 2) were placed down the middle of each plot to mark the sampling positions. Suction samples were taken one to two days before chemical treatment and then 2, 4, 8, 16, and 32 DAT. The samples were taken from either the left or right of the wooden pegs on alternate sampling dates to reduce sampling pressure on one area. The samples were collected in plastic pottles which were labelled and placed into a freezer (-20^{0}C) for later identification and counting of the arthropods.

Inflorescence and Crop Growth Assessment

Inflorescence numbers and damaged inflorescences were recorded at each sampling position by placing a 0.5 m x 0.5 m metal quadrat so that the wooden peg was in the bottom left corner (Plate 6). This meant that exactly the same area was assessed each time to reduce the sampling variability. Only inflorescences that possessed florets available for bee pollination were counted. Honey bees from hives located within close proximity to the crops and by feral bumble bees were responsible for pollination of inflorescences. Actual sampling dates are given in Table 11.

Plate 6. The 0.5 x 0.5 m quadrat and position used to assess inflorescence numbers and damage at each sampling.

Plant height and crop coverage was measured within the quadrats at each position during weeks 2 to 5. These two variables were recorded for covariance analysis in an attempt to explain some of the crop variation commonly found in white clover fields (Clifford 1987).

Table 11. Inflorescence sampling periods by field and sampling dates for each field.

Sampling period	Field			
	Macartney	Ryan	Heslop	Lowery
Week 1	22 Nov	22 Nov	*	19 Nov
Week 2	29 Nov	29 Nov	30 Nov	4 Dec
Week 4	17 Dec	17 Dec	16 Dec	16 Dec
Week 5	24 Dec	**	28 Dec	24 Dec
Final week	21 Jan	9 Jan	9 Jan	9 Jan

* Heslop's crop was later developing than the other crops and had no flowering inflorescences.
** Inflorescence counts not taken.

Yield Assessment

Some crops (Table 12) received a phenoxy herbicide spray ('MCPA' 375 g/litre MCPA, Dow Agrosciences) at 3.75 g a.i. with 12 ml surfactant ('Superstick' 100% non-ionic surfactants, Yates N.Z. Ltd.)/litre water on harvest strips to suppress clover growth and open up the sward for good penetration of a desiccant herbicide application before harvest (Table 12). All areas to be harvested within the plots were sprayed with diquat ('Reglone', 200 g/litre diquat, Crop Care N.Z. Ltd.) at 2.0 g a..i. with 12 ml 'Superstick'/litre water (Table 12).

Table 12. Pre-harvest herbicide application dates and harvest date for each field.

Herbicide application	Field			
	Macartney	Ryan	Heslop	Lowery
MCPA		11 Feb		5 & 8 Feb
Diquat	11 & 14 Feb	17 & 18 Feb	17 Feb	13 & 14 Feb
Harvest date	14 & 17 Feb	21 Feb	19 Feb	15 Feb

Strips 5 m x 0.45 m (2.25 m^2) were harvested in each plot at the 'edge', 2, 4, and 8 m positions where insect samples had been taken during the season. The strips were harvested using a rotary lawnmower. The harvested samples were placed in large paper bags and oven dried at 80 ^{0}C for several days until completely dry. Dry weights were recorded before the samples were thrashed for seed using a belt thresher. The resultant seed and debris were dressed using two air screen separators to remove the debris and light seed. Thousand seed weights (TSW) were determined by counting taking the average of three, 200-seed samples and multiplying by five. The seeds were counted by a 'Seedburo 801 Count-A-Pak' (USA) apparatus set at a sensitivity of 0.2 and vibration speed of 60.

Analysis of Results

Analysis of variance (ANOVA) was used to compare the densities of each arthropod species response to the treatments using the square root transformation to normalise the data. Transformed means were compared by using least significant differences ($LSD_{0.05}$). The insecticide-treated plots were compared with the control plots for each sampling period (pre, 2, 4, 8, 16, and 32 days after treatment, DAT). A similar analysis was used to detect differences between chemical treatments. ANOVA was also used to analyse yield data. All ANOVAs were performed using the Genstat® for Windows statistical package (© Lawes Agricultural Trust, IACR, Rothamsted, U.K.). For the 'double application' treatment, data were collected up to 55 DAT from the first spray application. However, to assist interpretation the results (unless indicated) show data up to and including 32 DAT only.

RESULTS

Due to a wetter-than-average growing season and mis-management of irrigation, the clover crop at Ryan's did not produce many flowers and growth was predominantly vegetative. The seed produced was of low quantity (approximately 120 kg/ha) and quality. The diversity and abundance of the insect pest fauna may have been influenced by the excessive vegetative growth as very low densities of PM were collected, while lucerneflea (*Sminthurus viridis* (L.)), a foliage feeder, were collected in very high densities. On this basis it was decided to remove Ryan's data and concentrate on the other three which represented good clover crops.

The insect pests collected in the suction samples are given in Table 2 (Chapter 2). Of the insect pests with densities > $1/m^2$, only results from the PM nymphs and adults and BGLA will be examined further in this study, with wheat bug adult and lucerneflea results presented in Appendix D.

Data for PM nymphs and adults and BGLA are presented as follows:

1. Overall differences (all treatments pooled) of densities between fields ('Between field differences').
2. Distribution (edge to 8 m) within the 'double application' control plots. These plots were sampled over the period of the whole experiment up to 55 DAT and provided information on the population trends for each species throughout the experiment ('Within field distribution').

3. For each species, the effect of each chemical treatment was compared with the control treatment at each sampling position into the crop (excluding the non-treated 8 m sampling position). The different application timings were pooled for each insecticide to indicate overall differences between chemicals ('Chemical effect').
4. The effects of application timing on each species within the 'First', 'Second' and 'Third' applications ('Application timing effect'). Comparisons are made at each sampling day within each chemical treatmen to determine whether the chemical effects were similar at each application.

Potato Mirid Nymphs

Between field differences

Of the three farms, Lowery's had consistently higher densities of PM nymphs over the season. The pooled PM nymph densities for all plots (excluding 8 m) at each site were significantly ($P< 0.05$) higher before chemical application ranging from $13/m^2$ to $4/m^2$ ($P< 0.01$) at 0 DAT compared with $2/m^2$ to $0.4/m^2$ ($P< 0.01$) at 16 DAT for Lowery and Macartney, respectively (at Heslop's the range was from $7/m^2$ to $0.7/m^2$, respectively).

Within field distribution

The density of PM nymphs was significantly ($P< 0.001$) higher at the crop edge on each sample date and decreased rapidly into the crop (Figure 19). PM nymphs were collected from the 8 m positions in low densities before treatment and at 4, 8, and 16 DAT. The highest density ($38/m^2$) occurred at the crop edges in late November (0 DAT) before treatment application, but decreased over time to $2/m^2$ by 31 DAT (late December).

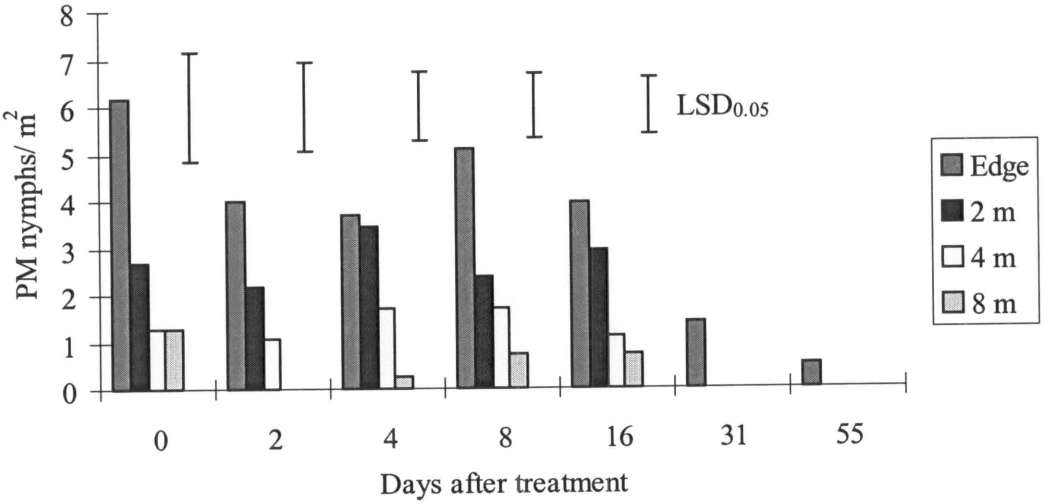


Figure 19. Potato mirid nymph densities (square root transformed) and at different sampling positions in white clover fields from the 'double application' control treated plots before and after treatment. $LSD_{0.05}$ is given for each sampling date.

Chemical effect

Lambda-cyhalothrin gave the largest percentage reduction (compared with the controls) of PM nymph densities over time compared with fluvalinate and pirimicarb (Table 13). Densities were significantly ($P< 0.01$) lower in the lambda-cyhalothrin plots at 2 to 16 DAT and ($P< 0.05$) at 32 DAT compared with the control plots. The fluvalinate plots had significantly ($P< 0.05$) fewer PM nymphs at 4 and 8 DAT, while pirimicarb did not have any effect.

Table 13. Square root transformed (and back-transformed) mean density (number/m^2) of pooled application times for potato mirid nymphs collected before and after spray treatment in white clover seed crops. Results are given for pooled 'edge', 2, and 4 m positions only.

	Days after treatment					
	pre	2	4	8	16	32
L-cyhalothrin	2.8 (7.8)	0.7 (0.5)	0.0 (0.0)	0.1 (0.0)	0.0 (0.0)	0.1 (0.0)
Fluvalinate	2.6 (6.8)	1.4 (2.0)	0.6 (0.4)	0.9 (0.8)	0.7 (0.5)	0.1 (0.0)
Pirimicarb	3.0 (9.0)	2.6 (6.8)	2.2 (4.8)	2.0 (4.0)	1.7 (2.9)	0.1 (0.0)
Control	2.6 (6.8)	2.3 (5.3)	1.9 (3.6)	1.7 (2.9)	1.5 (2.3)	0.3 (0.1)
$LSD_{0.05}$	1.0	1.0	1.1	0.8	0.9	0.2
L-cyhal v Control	ns	**	**	**	**	*
Fluvalinate vs Control	ns	ns	*	*	ns	ns
Pirim v Control	ns	ns	ns	ns	ns	ns

ns = not significant, * $P< 0.05$, ** $P< 0.01$.

However, in the edge position (where densities were greatest, Figure 19) there were significantly ($P< 0.001$) fewer PM nymphs in the lambda-cyhalothrin plots when all treatments were pooled and compared with the control treatments. In comparison, fluvalinate significantly ($P< 0.01$) reduced PM nymph densities at 2 and 4 DAT and ($P< 0.05$) at 8, 16 and 32 DAT compared with the control treatments.

Application timing effect

The pooled PM nymph densities (for all fields) at each of the application times were significantly different ($P< 0.05$) at 0 and 2 DAT, and ($P< 0.001$) at 4, 8, 16, and 32 DAT. At 0 DAT, pooled PM nymph densities were 6.2, 11.3, and 2.5/m^2 in the 'First', 'Second', and 'Third' applications, respectively (Figure 20).

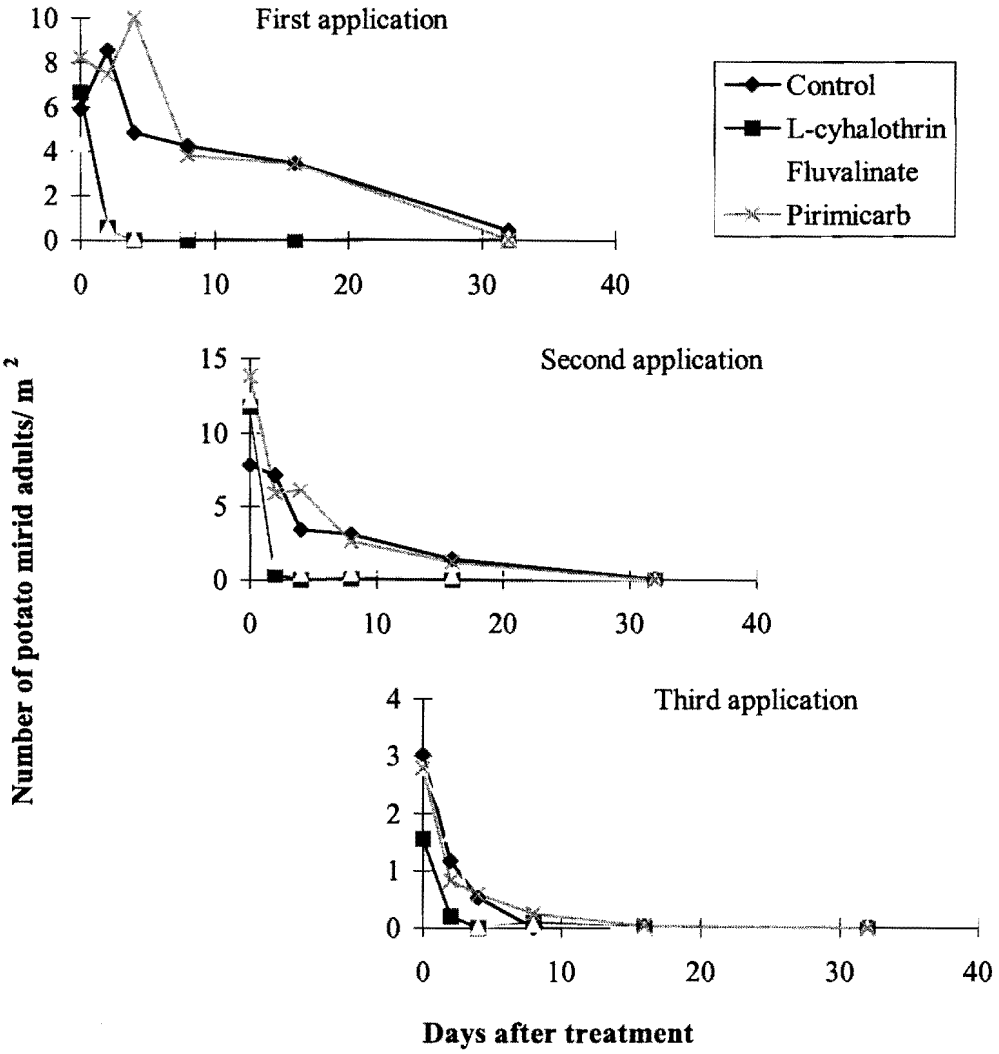


Figure 20. The effect of different spray timing treatments on PM nymph densities in white clover seed crops.

Table 14. Significant differences in mean PM nymph densities between the different insecticides and control at each sampling date, for each application ('First', 'Second', 'Third').

	Days after treatment					
	Pre	2	4	8	16	32
L-cyhalothrin	ns, ns, ns	*, ns, ns	**, *, ns	**, *, ns	**, *, ns	**, ns, ns
Fluvalinate	ns, ns, ns	*, ns, ns	**, ns, ns	*, ns, ns	ns, ns, ns	ns, ns, ns
Pirimicarb	ns, ns, ns	ns, ns, ns	ns, ns, ns	ns, ns, ns	ns, ns, ns	**, ns, ns

ns = not significant (P> 0.05), * = P< 0.05, ** = P< 0.01

Both the lambda-cyhalothrin and fluvalinate treatments prevented PM nymph densities peaking at 2 and 4 DAT following the first application (Figure 20). This was the most effective application

time for these two chemicals as they would protect the development of early first and second inflorescences (Figure 20, Table 14). Later applications tended to coincide with the natural decline in PM nymphal densities, although reductions in PM densities were still achieved.

Potato Mirid Adults

Between field differences

Of the three fields, Lowery's had consistently higher densities of PM adults compared with Heslop's and Macartney's. The pooled PM adult densities, however, were not significantly ($P > 0.05$) different between fields before treatment and at 2 and 4 DAT, but were significantly ($P < 0.001$, 0.01, and 0.05) higher at Lowery's at 8, 16, and 32 DAT, respectively. Adult densities ranged from 0.5 to 0.0/m^2 at 8 DAT, 1.6 to 0.2/m^2 at 16 DAT, and 1.3 to 0.1/m^2 at 32 DAT for the Lowery and Heslop fields, respectively.

Within field distribution

Numbers of PM adults were very low (mostly < 1/m^2) during the experimental period, increasing only slightly over time to reach a maximum 2.4/m^2 at the 2 m sampling position at 16 DAT in the 'double application' control treatment (Figure 21). The main concentration of PM adults occurred within 4 m of the crop edge, and negligible numbers were collected at 8 m into the crop during the season. There was no significant ($P > 0.05$) difference in PM adult densities between the sampling positions on each of the sampling dates.

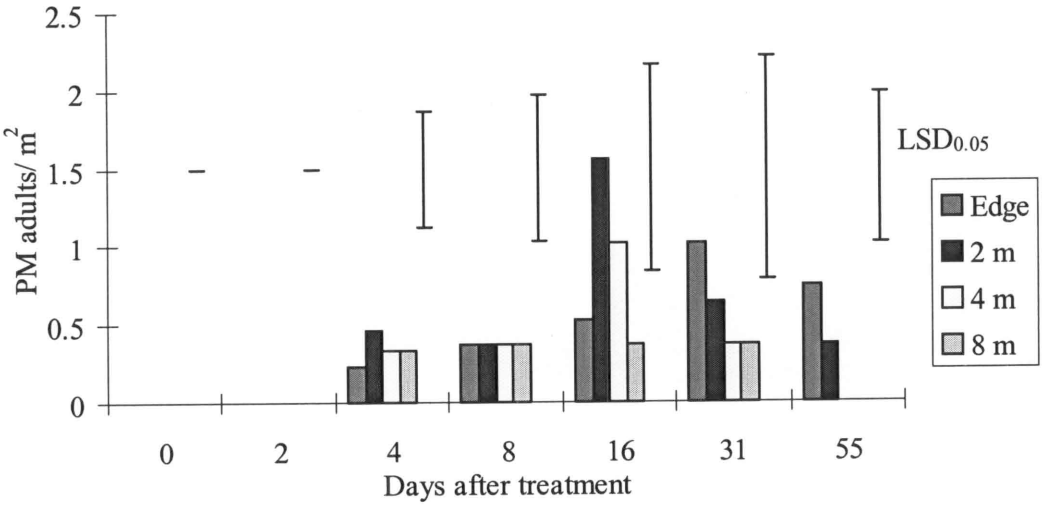


Figure 21. Potato mirid adult densities (square root transformed) and at different sampling positions in white clover fields from the 'double application' control treated plots before and after treatment. $LSD_{0.05}$ is given for each sampling date.

Chemical effect

When data for the three applications were pooled over the sites, PM adults were significantly ($P< 0.05$ and 0.01) reduced only by lambda-cyhalothrin compared with the control treatment at 8 and 16 DAT, respectively (Table 15). The largest contributing influence on this overall result was the significant ($P< 0.01$ and 0.05) decreases in PM adult densities at the 2 and 4 m sampling positions with lambda-cyhalothrin treatment (8 and 16 DAT, respectively).

Table 15. Square root transformed (and back-transformed) mean density (number/m^2) of pooled application times for potato mirid adults collected before and after spray treatment in white clover seed crops. Results are given for pooled 'edge', 2, and 4 m positions only.

	Days after treatment					
	pre	2	4	8	16	32
L-cyhalothrin	0.3 (0.1)	0.1 (0.0)	0.0 (0.0)	0.2 (0.0)	0.3 (0.1)	0.5 (0.3)
Fluvalinate	0.3 (0.1)	0.4 (0.2)	0.1 (0.0)	0.4 (0.2)	0.6 (0.4)	0.7 (0.5)
Pirimicarb	0.4 (0.2)	0.3 (0.1)	0.3 (0.1)	0.5 (0.3)	1.2 (1.4)	0.8 (0.6)
Control	0.5 (0.3)	0.4 (0.2)	0.4 (0.2)	0.6 (0.4)	1.0 (1.0)	0.6 (0.4)
$LSD_{0.05}$	0.3	0.3	0.6	0.3	0.4	0.8
L-cyhal v Control	ns	ns	ns	*	**	ns
Fluvalinate vs Control	ns	ns	ns	ns	ns	ns
Pirim v Control	ns	ns	ns	ns	ns	ns

ns = not significant, * $P< 0.05$, ** $P< 0.01$

Application timing effect

The pooled PM adult densities (for all fields) at each of the application times were significantly different ($P< 0.001$) at 0, 2 and 4 DAT, ($P< 0.05$) at 8 DAT, and ($P< 0.01$) at 16, and 32 DAT. At 16 DAT the densities of PM adults were 0.2, 1.2, and 0.4/m^2 in the 'First', 'Second', and 'Third' applications, respectively (Figure 22).

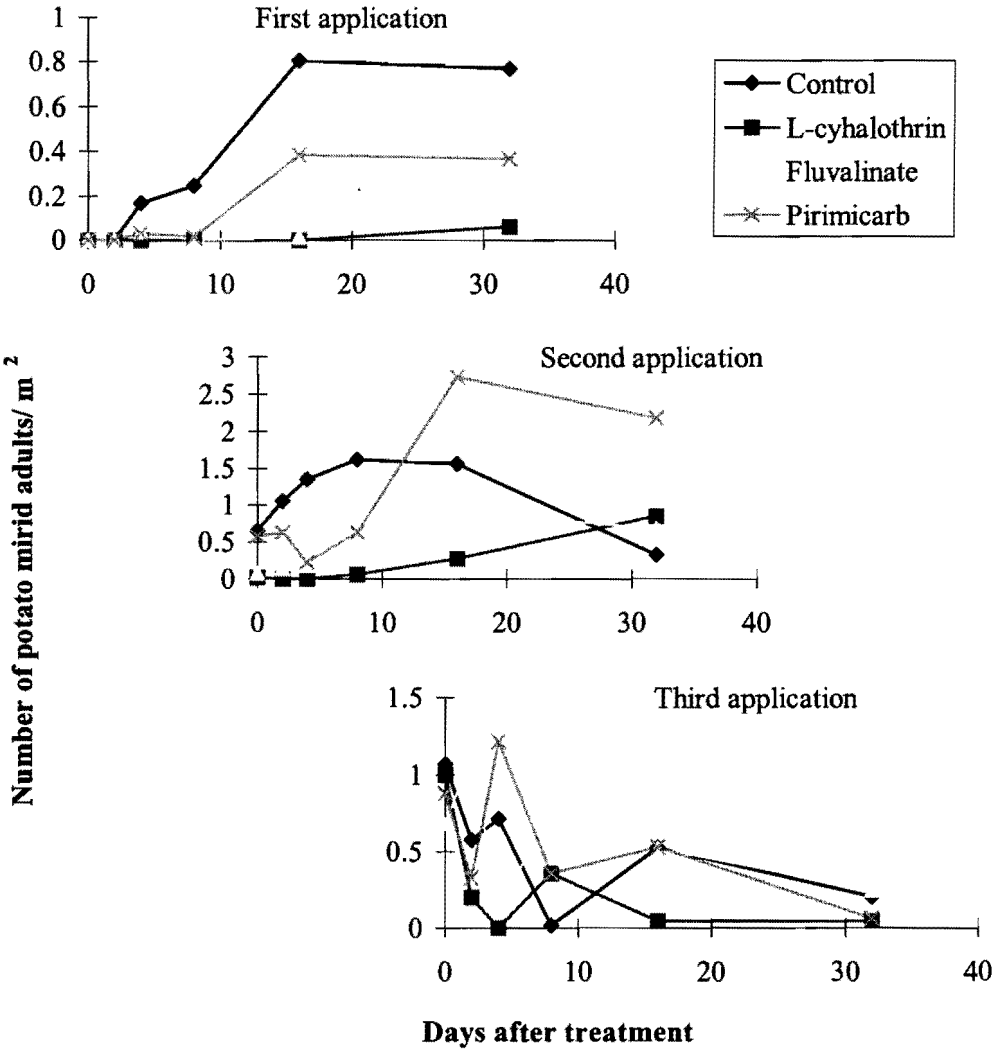


Figure 22. The effect of different spray timing treatments on PM adult densities in white clover seed crops.

Table 16. Significant differences in mean PM adult densities between the different insecticides and control at each sampling date, for each application ('First', 'Second', 'Third').

	Days after treatment					
	Pre	2	4	8	16	32
L-cyhalothrin	ns, ns, ns	ns, ***, ns	ns, **, ns	ns, **, ns	*, ns, ns	ns, ns, ns
Fluvalinate	ns, ns, ns	ns, *, ns	ns, ns, ns	ns, ns, ns	*, ns, ns	ns, ns, ns
Pirimicarb	ns, ns, ns	ns, ns, ns	ns, ns, ns	ns, ns, ns	ns, ns, ns	ns, ns, ns

ns = not significant (P> 0.05), * = P< 0.05, ** = P< 0.01, *** = P< 0.001

The second application (especially for the lambda-cyhalothrin treatment) had the greatest overall impact on reducing PM adult densities compared with the other applications (Table 16).

Bluegreen Lucerne Aphid

Between field differences

Overall, there was a significant (P< 0.001) difference before application and at 2 DAT, (P< 0.01) at 4, 8, and 16 DAT and (P<0.05) at 32 DAT in pooled BGLA densities between the three experimental fields. Macartney's field had the highest overall pooled density of BGLA at 2 DAT peaking at 135/m^2 compared with 9/m^2 at Heslop's (P< 0.001).

Within field distribution

BGLA densities reached a maximum of 224/m^2 at 2 DAT at the 2 m sampling position (Figure 23). BGLA densities were uniform and not significantly (P> 0.05) different across the sampling positions at each sampling date in the 'double application' control plots.

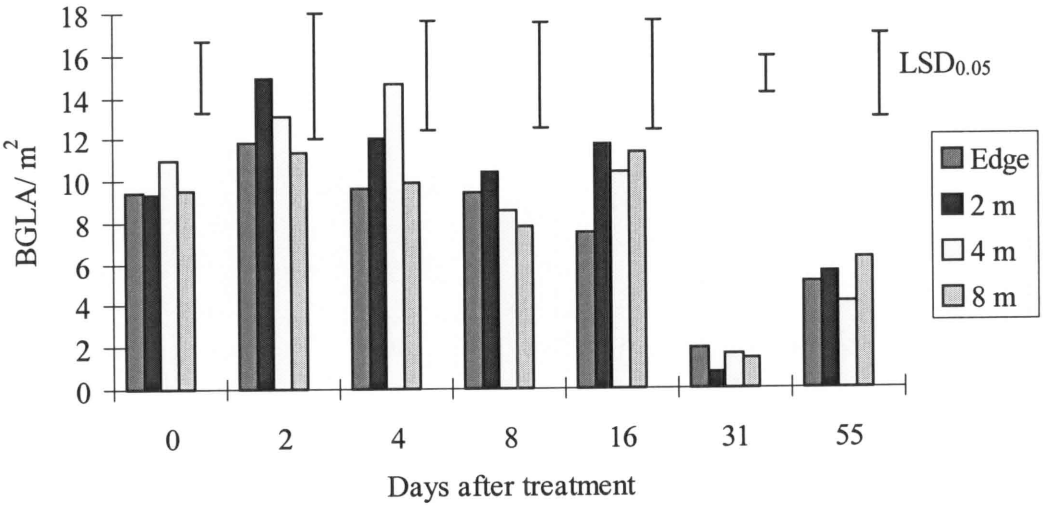


Figure 23. Bluegreen lucerne aphid densities (square root transformed) at different sampling positions in white clover fields from the 'double application' control treated plots before and after treatment. $LSD_{0.05}$ is given for each sampling date.

Chemical effect

Of the chemical treatments, pirimicarb significantly reduced BGLA densities for a longer period than lambda-cyhalothrin and fluvalinate when compared with the control treatment (Table 17).

Table 17. Square root transformed (and back-transformed) mean density (number/m^2) of pooled application times for bluegreen lucerne aphids collected before and after spray treatment in white clover seed crops. Results are given for pooled 'edge', 2, and 4 m positions only.

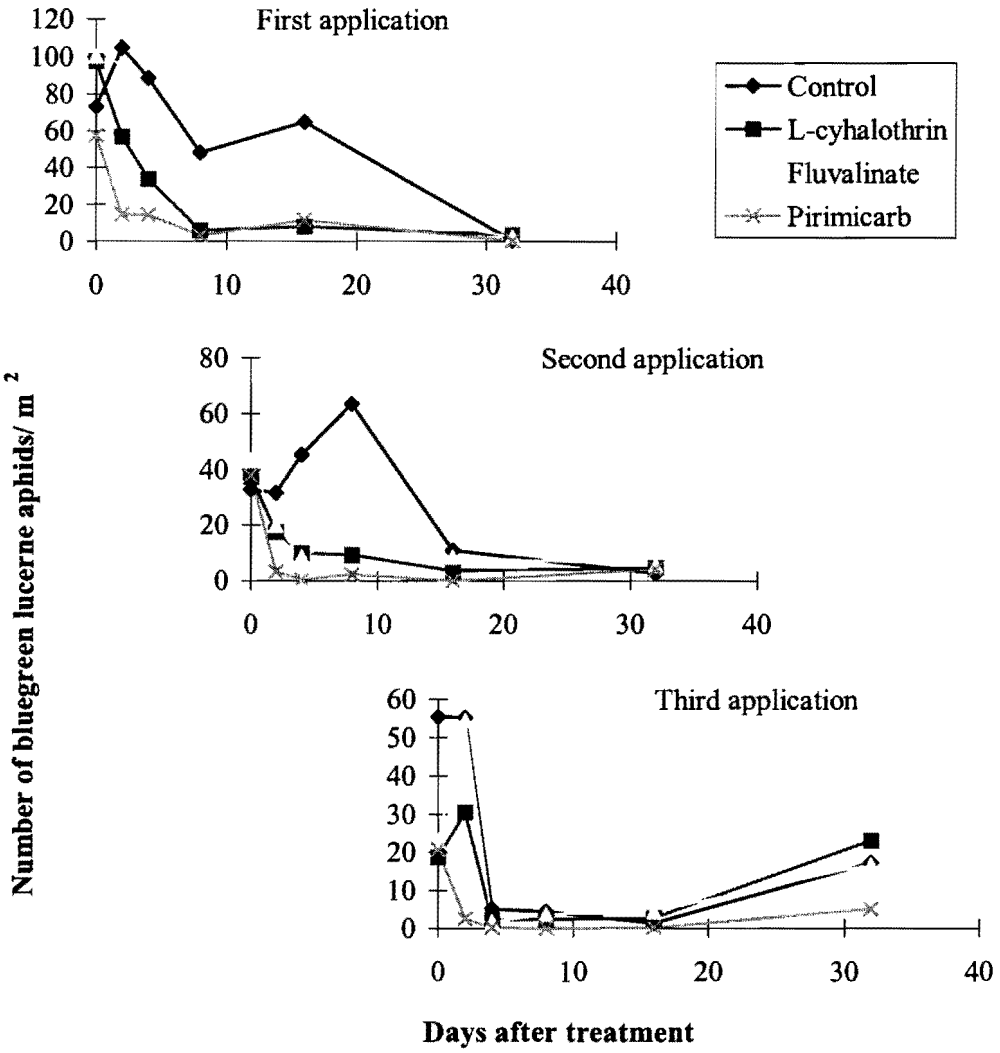
	Days after treatment					
	pre	2	4	8	16	32
L-cyhalothrin	8.1 (66)	5.8 (34)	4.3 (18)	2.4 (5.8)	2.6 (6.8)	3.0 (9.0)
Fluvalinate	7.9 (62)	7.9 (62)	5.1 (26)	4.0 (16)	3.6 (13)	2.7 (7.3)
Pirimicarb	7.6 (58)	2.8 (7.8)	2.1 (4.4)	1.4 (2.0)	1.7 (2.9)	1.6 (2.6)
Control	7.9 (62)	9.1 (83)	7.7 (59)	6.6 (44)	5.6 (31)	2.2 (4.8)
$LSD_{0.05}$	1.8	3.8	2.4	4.5	4.1	1.3
L-cyhal v Control	ns	ns	*	ns	ns	ns
Fluvalinate vs Control	ns	ns	*	ns	ns	ns
Pirim v Control	ns	**	***	*	ns	ns

ns = not significant, * P< 0.05, ** P< 0.01, *** P< 0.001

Application timing effect

The pooled treatment data (for all fields) showed that the BGLA densities at each of the application times was significantly different (P< 0.01) at 4 DAT, (P< 0.05) at 8, and 16 DAT, and

(P< 0.001) at 32 DAT. At 4 DAT pooled BGLA densities were 47, 11, and 2/m^2 in the 'First', 'Second', and 'Third' applications, respectively (Figure 24).



1st flower development	2nd flower development	Crop at full flower	Seed fill and maturation

Figure 24. The effect of different spray timing treatments on BGLA densities in white clover seed crops.

Overall, pirimicarb gave the quickest and longest period of BGLA control (Table 17) and was the only treatment that significantly (P< 0.05) reduced BGLA densities below those of the control treatment at 8 DAT (Second application) and 32 DAT (Third application) (Figure 24). However, the longer-term effects of pirimicarb, lambda-cyhalothrin, and, to a lesser degree fluvalinate (during the first application), kept BGLA densities low during the white clover inflorescence developmental period.

Inflorescence and Crop Growth Assessment

There were significant (P< 0.001) differences in the densities of inflorescence between fields from week 2 to week 7 (Figure 25). The highest inflorescence densities were recorded at Lowery's (209/m^2) during week 2 (4 December), Heslop's (136/m^2) and Macartney's (144/m^2) during week 4 (16 and 17 December), respectively.

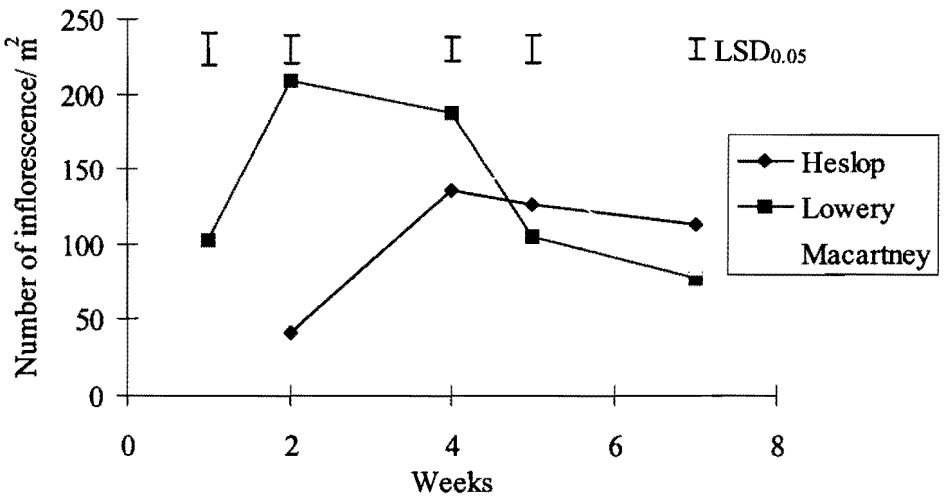


Figure 25. Flowering patterns from each field taken from the pooled means at each sampling date (week 1 = 19-22 November to week 7 = 9 January).

When all treatments were pooled, there were significant (P< 0.001) differences in inflorescence densities recorded at each sampling position during weeks 1 to 4 (Figure 26a). The 2 m position had consistently higher inflorescence densities, whereas the edge position had the lowest. Flowering in all fields peaked during week 4, around 17 December (Figure 26a). There were no significant (P> 0.05) differences in inflorescence densities between treatments during each sampling date or at the different sampling positions. There were no significant (P> 0.05) differences in inflorescence densities at each sampling date between the different application times.

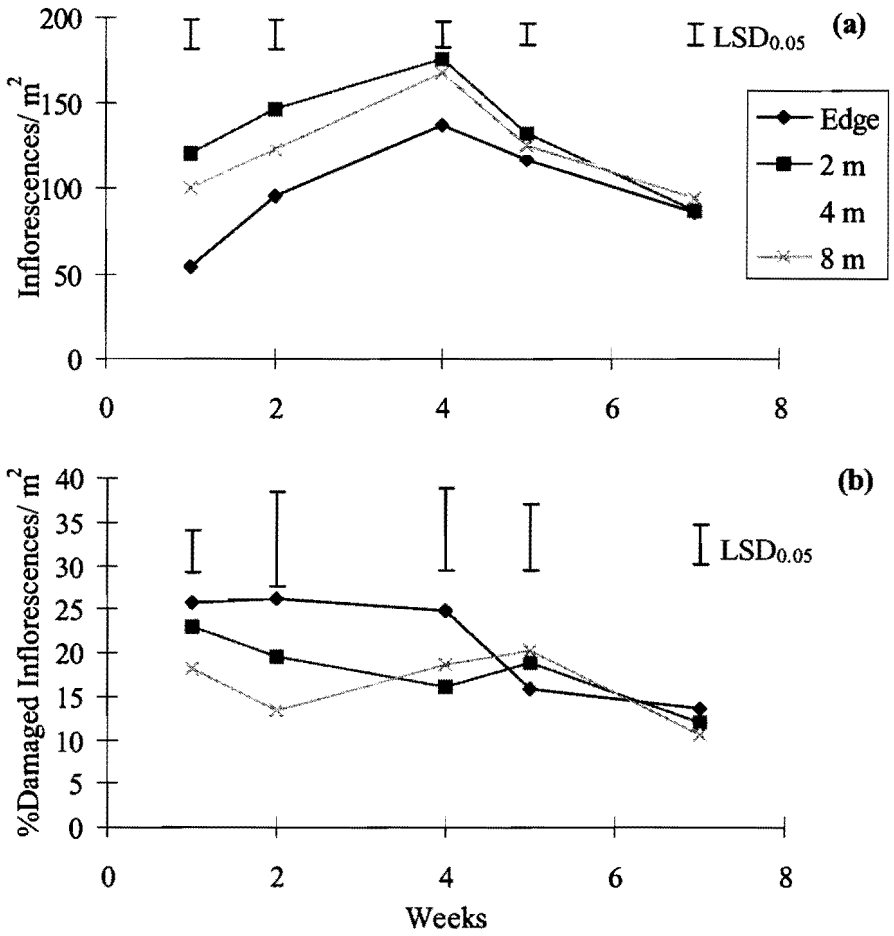


Figure 26. Pooled inflorescence densities from all treatments (a) and %damage (b) at each sampling position over time (week 1 = 19-22 November to week 7 = 9 January).

There were significant ($P< 0.05$, <0.01, and < 0.001) differences in the proportion of damaged inflorescences (% Damaged) at the different sampling positions during weeks 1, 2, and 4, respectively (Figure 26b). Overall, a decrease in the proportion of damaged inflorescences from the edge into the white clover crop occurred at each sampling period.

Yield Assessment

When all data were pooled, there were significant ($P< 0.001$, $LSD_{0.05}$ 7.3) differences in seed yields between the three fields. The highest yield occurred at Lowery's (58.9 g/m^2), followed by Heslop's (51.8 g/m^2) and Macartney's (35.9 g/m^2).

When all seed yield data were pooled, there were no significant ($P> 0.05$) differences between the insecticide treatments and the control. The highest seed yields occurred in the lambda-cyhalothrin

treatment (52.3 g/m^2) which was higher (P = 0.052) than the control at 42.57 g/m^2 (fluvalinate 50.1 and pirimicarb 45.8 g/m^2).

Overall, when all treatments were pooled, there were significant (P< 0.001) differences in white clover seed yields between the different sampling positions. The edge position (38 g/m^2) yielded less seed than the other sampling positions (at 2 m, 52.1; 4 m, 53; and 8 m, 52.4 g/m^2).

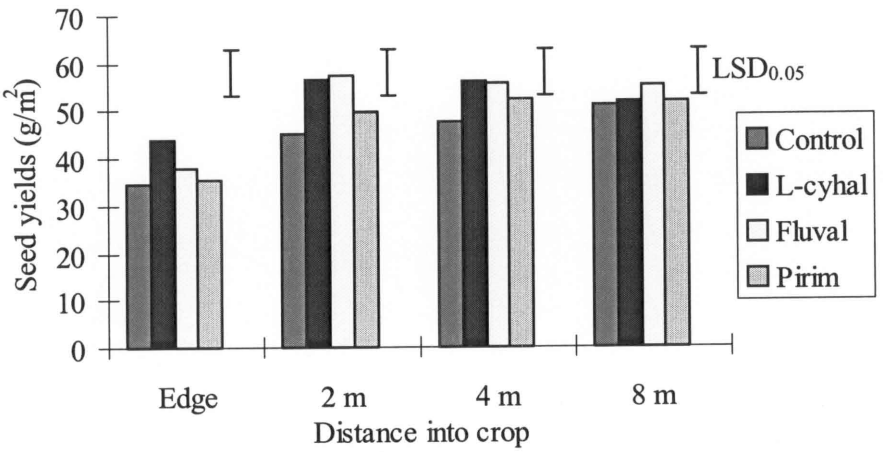


Figure 27. White clover seed yields from different insecticide treatments at different sampling positions within the crop. $LSD_{0.05}$ given for each sampling position.

Both the lambda-cyhalothrin and fluvalinate treatments significantly (P< 0.05) increased white clover seed yields at the 2 m positions compared with the control treatments (Figure 27).

There were significant (P< 0.001) differences in the pooled treatment seed yields collected from each application treatment. The 'first' application had the highest overall seed yield (56.7 g/m^2) followed by the 'third' (52.4 g/m^2), 'double' (38 g/m^2), and 'second' (41.3 g/m^2) applications.

The variability found in the seed yields was not accounted for by using any of the inflorescence, crop height, or crop coverage data as covariants in subsequent analysis. The only significant relationship found was between PM nymph and adult densities and seed yields. The high to low PM densities from the edge into the crop corresponded with low to high seed yields. When PM nymph and adult densities were regressed against seed yields at the same sampling positions significant (P< 0.05) linear and quadratic (respectively) relationships were found and are described by the following equations:

$$\text{Yield} = 54.2 - 0.38\,x \quad (R^2 = 93.8\%), \text{ where } x = \text{PM nymph density}$$

$$\text{Yield} = 51.47 + 5.41x - 2.98x^2 \quad (R^2 = 99\%), \text{ where } x = \text{PM adult density}$$

Despite the fact that BGLA densities were reduced by pirimicarb, this did not result in significantly higher seed yields from these plots, indicating that BGLA did not significantly contribute to seed yield loss.

DISCUSSION

In general, the season produced average seed yields (approximately 300 kg/ha) throughout the Canterbury growing region (Peter Clifford pers. comm.). Most seed losses during the season were due to a wet harvesting period. The MCPA applications to plots were very effective at halting vegetative growth and opening up the canopy to allow penetration of the diquat application(s). However, the effect of the wet harvesting period is further illustrated by the amount of herbicide that was required to desiccate the crop for harvest. An extreme example of the influence of a wet season was the loss of Ryan's crop due to over-irrigation early in the season and the resultant vegetative rather than reproductive growth. The loss of Ryan's crop unfortunately reduced the number of field replicates from four to three. The measurements of crop height and crop cover did not help explain any of the variation of seed yield found within the fields. Additional replication of treatments within the fields would have reduced the variation within each field, however, the amount of time required for sampling and data collection would have increased.

Of the insect pests collected, PM nymphs and adults were the only pests whose densities (from the different sampling positions) correlated with seed yields. Their distribution within all crops was high in the crop edges and decreased into the crop, which is consistent with the results of the crop monitoring experiments (Chapter 2 and 3) and other studies (Schroeder 1995; Schroeder and Clifford 1996). PM nymphs were already present in high densities before the insecticide applications, but were controlled by the first application of lambda-cyhalothrin and fluvalinate. Of these insecticides, lambda-cyhalothrin provided a quicker knock-down and longer residual control, especially when applied in late November (first application) and early December (second application), respectively. Both lambda-cyhalothrin and fluvalinate suppressed PM nymph densities to low levels for the remainder of the experimental period when applied in late November. These insecticides could be used as a prophylactic treatment to suppress PM nymphs when applied during the white clover inflorescence developmental period. The insecticide could

be applied to a 10 metre strip around the crop margins where PM nymphs occur in the highest density. Pirimicarb was not effective in reducing PM densities (Table 13).

There was a 16-fold decrease in peak densities between PM nymphs and adults. While natural mortality could account for this, it is considered more likely that dispersal of adults occurred. Potato mirid adults are strong fliers, often flying away when approached with the suction sampler. Potato mirid adults are a pest of pistachio fruit in California, flying into the pistachio crops from uncontrolled weedy verges and causing epicarp lesion symptoms from feeding puncture wound injury (Uyemoto *et al.*, 1986; Michailides *et al.*, 1987). Control of PM in California is obtained by frequent disking and mowing of the verges and the application of insecticides (carbaryl and permethrin) before adult emergence. Because white clover crops are grown to the edge of the field, cultivation of weedy verges is not practical. Other cultural management options may include the planting of trap crops around the field edges, although the extra effort and management may not prove worthwhile.

Bluegreen lucerne aphid densities were relatively uniform across the sampling positions over time and peaked in early December followed by a smaller peak in mid December (Figure 23). Pirimicarb had the greatest effect on reducing BGLA populations followed by lambda-cyhalothrin and fluvalinate.

Previously, the necessity for insecticidal control of clover casebearer moth was determined by using a formula based on inflorescence development, density of moths captured, chemical costs and seed yield value (Pearson 1982). It became common farm practice to spray insecticides, which were all toxic to bees, early in December when Huia had started flowering. This experiment has shown that the first application of the lambda-cyhalothrin and fluvalinate gave the best suppression of PM nymphs and adults, whereas, the first application of all three insecticides gave good suppression of BGLA over the inflorescence developmental period. This application was approximately two weeks earlier (late-November) than traditionally timed applications. The prophylactic use of these chemicals to provide plant protection over a critical growth period was shown to be the most effective. The univoltine PM is controlled before adult emergence and dispersion, while large aphid populations do not appear to establish from flights occurring later in the season. Although the prophylactic approach acts as an 'insurance' to growers, it does not address the problem of over-application of insecticides. A more detailed study of the feeding injury caused by each species is required to determine the specific pest-plant interactions and their

impacts on seed yields. The development of action thresholds in accordance with IPM principles would also help ensure that the unnecessary use of chemicals does not occur.

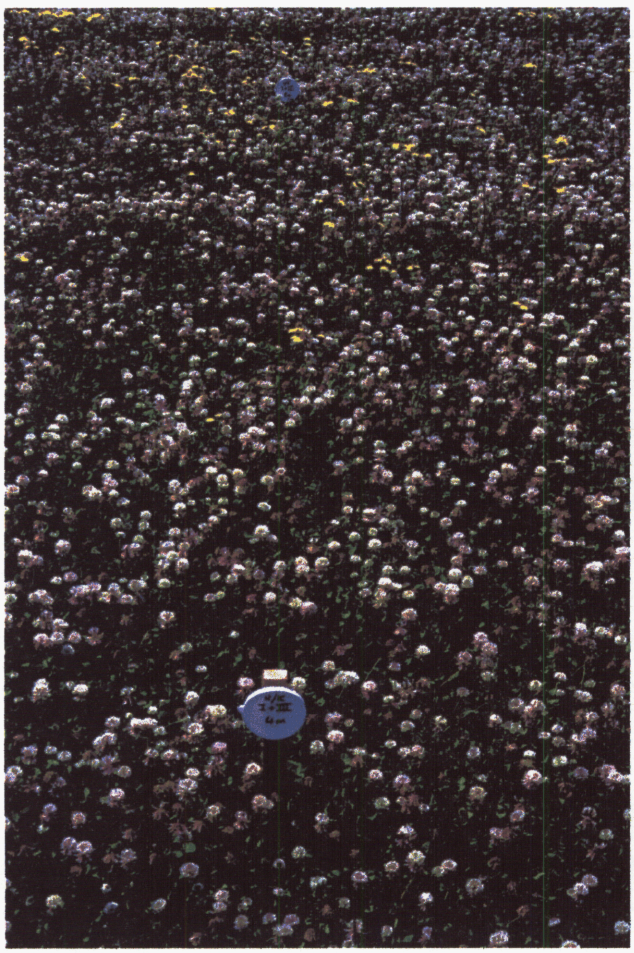


Plate 7. Good density of white clover plants and flowering in Heslop's crop compared with Plate 8.

Plate 8. Poor plant density and flowering in a neighbouring plot at the same date. The open canopy and low plant density are usually a result of lighter soils that are prone to drying out, but it can also be the result of poor crop management. In this case, the irrigator constantly missed this area of the crop.

Inflorescence numbers were lower at the crop edge than at other sampling positions and the proportion of damage was, in general, higher at the edge compared with further into the crop. Correspondingly, the seed yields at the edge of the crops were significantly lower. When lambda-cyhalothrin and fluvalinate reduced PM densities there were increases in seed yields. When BGLA densities alone were reduced by the application of pirimicarb, there was no increase in seed yield, indicating that BGLA did not contribute to seed yield loss. The impact of PM and BGLA feeding injury requires further study. However, in this study, it is clear that PM feeding caused the majority of seed yield loss. The feeding impacts of both pests will be discussed further in Chapter 5 and 7. It was expected that the 'double' applications of insecticide would give a longer period of pest control resulting in higher seed yields. This, however, was not the case. Several factors may have influenced this result. These include the increased mechanical injury caused by higher sampling pressure and the phototoxic effect of some chemicals on plants.

The chemical costs based on the recommended application rates (based on pricing from Pyne Gould Guiness Ltd., 26 May 1998) are: lambda-cyhalothrin $25.44/ha, fluvalinate $29.59/ha and pirimicarb $21.99/ha. Considering that pirimicarb has a very limited spectrum of activity, farmers would be advised to use lambda-cyhalothrin, which has a faster and longer lasting effects against PM and BGLA. However, the very limited distribution of PM in the field edges may mean that control of this pest alone is uneconomic. The specific pest-plant interactions for PM and BGLA require identification to determine the full effect of their feeding injury on plant growth and seed yields. The experiment presented in the next chapter investigates these relationships within field cages.

CHAPTER FIVE

THE EFFECT OF POTATO MIRID AND BLUEGREEN LUCERNE APHID ON WHITE CLOVER SEED PRODUCTION IN FIELD CAGES

INTRODUCTION

The Use of Field Cages

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, Wratten 1975, Simmons and Yeargan 1990, Pearson 1991). Large cages (e.g., 8 m^2, 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 (e.g., 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 assessment 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. The use of field cages to assess yield losses may also be the precursor for the development of action thresholds for control application within crops.

Field Cage Experiments in White Clover

Pearson (1991) studied the effect of meadow spittlebug (*Philaenus spumarius*) and Australian crop mirid (ACM, *Sidnia kinbergi*) 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. Densities of one ACM per plant (released on 2 December during inflorescence development) caused a 50% reduction in the number of inflorescences, an 18% reduction in the number of buds produced on each inflorescence, and a 26% reduction in the number of buds that produced florets. The number of seeds per inflorescence was also reduced.

Subsequent work by Schroeder and Clifford (1995), however, has found potato mirid (PM) and bluegreen lucerne aphid (BGLA) were the two most abundant insect pests collected during the 1994-95 growing season in 24 Canterbury white clover (cv 'Huia') seed crops. Both species occurred early in the growing season (mid November to late December) when maximum plant growth and inflorescence development was occurring. The highest density of PM nymphs ($40/m^2$) occurred along the crop edge (0-1 m), while BGLA numbers reached a maximum of $800/m^2$ within fields. Other insect pests described by Wightman and Macfarlane (1981) (e.g., ACM, brown shield bug and wheat bug) occurred later in the growing season (mid January) during seed maturation and were not considered major pests of white clover seed crops.

Schroeder *et al.* (1997) used the same cages as Pearson (1991) to investigate the impact of PM in a 1993-94 field experiment situated in a 'Huia' nucleus seed crop at Lincoln. The experimental area had uniform plant growth and responses over the season. There were no significant ($P > 0.05$) differences in seed production between the uncaged and caged control plots. When tagged stolons were compared between treatments, no significant differences between plant growth and flowering pattern were observed, however, inflorescences were reduced as mirid numbers increased. When total plot flowering and yield components were compared, a significant negative quadratic relationship between total inflorescences and first quality seed yield with increasing mirid intensity was demonstrated. For second quality seed yield, a negative linear relationship was observed. A positive linear relationship between undamaged inflorescences and total yield per plot was also demonstrated. On the basis of current returns for white clover seed ($4/kg), losses of up to $740/ha were estimated.

BGLA was first reported in New Zealand in 1975 by Cox and Dale (1977) five months after it had arrived in Australia (Cameron and Walker 1989). BGLA has been associated with stunting and

deformation of lucerne plants and significant yield losses (Summers *et al.* 1984) and Trought (1977) predicted a 20% seed yield loss could occur in white clover crops with infestations above 16 aphids per inflorescence. Stufkens (pers. comm.) suggested that any impact caused by BGLA feeding is most likely to be detectable in a decrease in white clover seed quality (measured by the thousand seed weight). However, the damage caused by BGLA to white clover is not fully understood and requires further investigation.

Following the 1993-94 cage experiment conducted in a nucleus 'Huia' crop there were two seasons (1994-95 and 1995-96) in which similar cage experiments were conducted. The first experiment during the 1994-95 season was carried out in a row-spaced 'Huia' crop at Leeston (30 km south of Lincoln). The treatments included three PM, three ACM and one brown shield bug intensity based on the number of stolons per cage, and uncaged and two control caged plots per replicate. The treatments were replicated five times in a randomised block design. The season was colder and wetter than average, affecting plant growth and development and the survival of insects placed into the cages.

Although the experimental area was chosen for its low variability in plant density and growth the seasonal conditions exaggerated the variability between and within blocks. The plant variability was influenced by the accidental application of a phenoxy herbicide residue from a faulty knapsack sprayer when the pre-infestation clean-up spray was applied. The two control cages in each block were found to have significantly ($P< 0.05$) different seed yields from each other as well as other measured variables (e.g., total inflorescence numbers). Flowering data, dryweights and other variables (e.g., plant height) were used as covariates in statistical analysis to account for this variability, but these did not improve the interpretation of results and the data were discarded.

During the 1995-96 season, six PM treatments (uncaged and caged controls, 8, 16, 20(1), 20(2) and 32 PM per cage) were applied. The two '20 PM' treatments were suction sampled two (20(1)) and four weeks (20(2)) after PM infestation to indicate PM survival over the experimental period. During the experimental period several blocks received approximately 120 mm of water from an irrigation gun which failed to turn off at the end of a run in a neighbouring field. Plant growth within the affected area switched from reproductive to vegetative resulting, again, in large variability within the experimental area. Statistical analysis of data showed more variability within the blocks than between blocks. This variability could not be explained using covariant combinations similar to the 1994-95 season analysis and the data were again discarded.

The lessons learned from two seasons 'failed' caged experimentation were as follows.

1. High variability in crop performance occurs even within small areas of a crop.
2. To reduce variability within the experiment there is a need for:
    a) more replication of treatments (minimum 5);
    b) better control of events within the treatment area (e.g., co-ordination with grower practices like irrigation, etc.);
    c) control of plant variability by using clones or plants grown in similar conditions.
3. The BGLA cages needed to be modified to avoid invasion by predators or escape of BGLA.
4. A clean (e.g., laboratory reared) source of BGLA was needed to prevent contamination by parasitoids and predators like *Aphidius* spp. and Tasmanian lacewing.
5. Using an infestation density more applicable to conversion to threshold levels in the field than using a per stolon intensity (as in the 1992-93 season, Schroeder 1995).
6. PM and ACM produced a second generation within cages that is likely to have influenced the amount of plant injury observed. Closer observation was required to identify this and to stop the experiment before the second generation.

The experiences gained from the 1994-96 seasons greatly influenced the experimental design and methodology used in the field cage experiment conducted during the 1996-97 season.

The experiment reported here investigates the effects of BGLA feeding injury on plant development at several growth stages and the effects of different intensities of potato mirids (similar to field numbers) on plant growth and seed yields within field cages.

MATERIALS AND METHODS

Plant Management

Two white clover cultivars were used in the experiment; 'Huia' and a high seed-yielding 'Huia'-type clone with a similar flowering pattern. As white clover does not produce viable seed without cross pollination it was necessary to include 'Huia' for cross pollination purposes. Clonal material was used to reduce variability between plants.

Clone plant propagation

The clonal plants originated from two parent plants that were part of a high seed-yielding selection field experiment conducted during the 1992-93 season. This was the fourth successive year that the clones had been taken from the previous season's clones. A section of stolon with two to three growing nodes (refer Figure 28) was taken from the parent plants (3 and 6 May) and transplanted into small plastic potting bags (PB3) containing a 50:50 peat to sand and soil mixture. The plants were kept in a glasshouse (20^{0}C) until they were established. They were later transferred to a shade house in July and then placed outdoors to harden off in winter conditions before planting in the field.

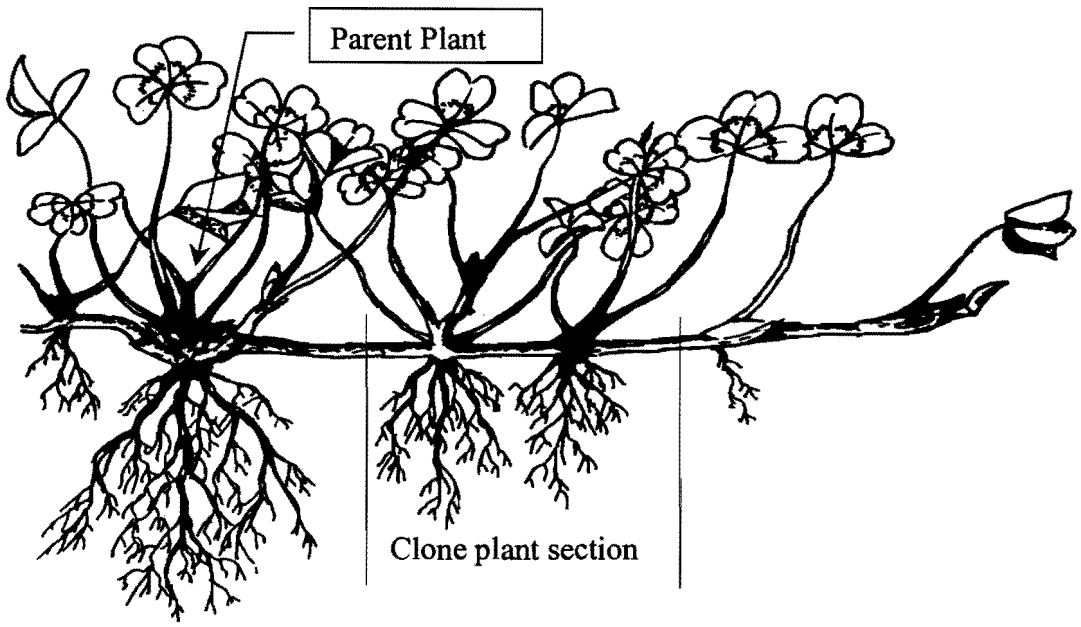


Figure 28. White clover stolon showing section used for clone plants.

'Huia' plant propagation

The 'Huia' seed was collected from a cage experiment conducted during the 1993-94 season (refer Schroeder 1995) in a nucleus seed crop grown at Lincoln. The seed was lightly scarified using fine sand paper. Seed viability was tested by placing 100 seeds in each of eight petri dishes lined with damp filter paper. Overall, the seed viability ranged between 69 to 83% and averaged 80% (International Seed Testing Association 1993). Trays containing potting mix (1:1 peat and sand) were sown with three seeds per hole on 29 April. Nine trays were sown and placed in a glasshouse and the resultant seedlings were thinned to one per hole to give 25 evenly spaced plants per tray. The trays were then transferred to a shade house (July) for two weeks and then outdoors to harden off before planting in the field.

Field Site Preparation

The experiment was conducted at the AgResearch farm, Lincoln, on a predominantly Templeton silt loam soil. The field was previously in pasture that had been ploughed in late summer and fallowed during winter. Two days before planting the experimental area was lightly harrowed to remove weeds and to loosen the soil.

Each cage plot was marked out and the plants transplanted on 17 and 18 September. Three clones and three 'Huia' plants were planted in each plot. A piece of 10 cm wide builders' damp proof coarse (DPC) paper was positioned with wire pegs between the two plant types to act as a barrier (Figure 29), to keep them separated for later inflorescence and seed yield assessments.

On 26 September and 14 November the experimental area received 4 cm of irrigation. Soil samples showed a boron deficiency, therefore, a mineral supplement was sprayed on all plots as 10 g 'fetrilon combi' (Mg 5.4%, S 3%, Mn 4%, Fe 4%, Cu 1.5%, Zn 1.5%, B 0.5%, Mo 0.1%, and Co 0.005%) in 10 litres of water on 12 November.

Cage Design

Two different cage types were used in the experiment (refer to Plates 9 and 10).

1) The cages used to contain the BGLA were made from four (900 x 750 mm) wooden frames strapped together and covered with a pre-sown mesh net. The net was made of fine Italian voile to prevent the loss or invasion of aphids or other insects into the cage. The net was

secured to the wooden frame by stapling a strip of 15 mm nylon strapping around the base and top. The top was secured by pulling a sewn in draw-string tight and winding the string around the gathered material. The cages were secured to the ground with 300 mm steel pins and by mounding up and packing soil around the bases.

2) The cages containing the PM comprised four 900 x 900 mm 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 held together by metal clamps. The lid consisted of a square piece of nylon screen which was stapled to the top of one panel. The other three edges were held down by strips of Velcro® sewn on the lid and glued to the top of the other three wooden panels. The cages were secured to the ground in a manner similar to the BGLA cages.

All cages were erected and secured on the plots during 8-9 November.

Experimental Design

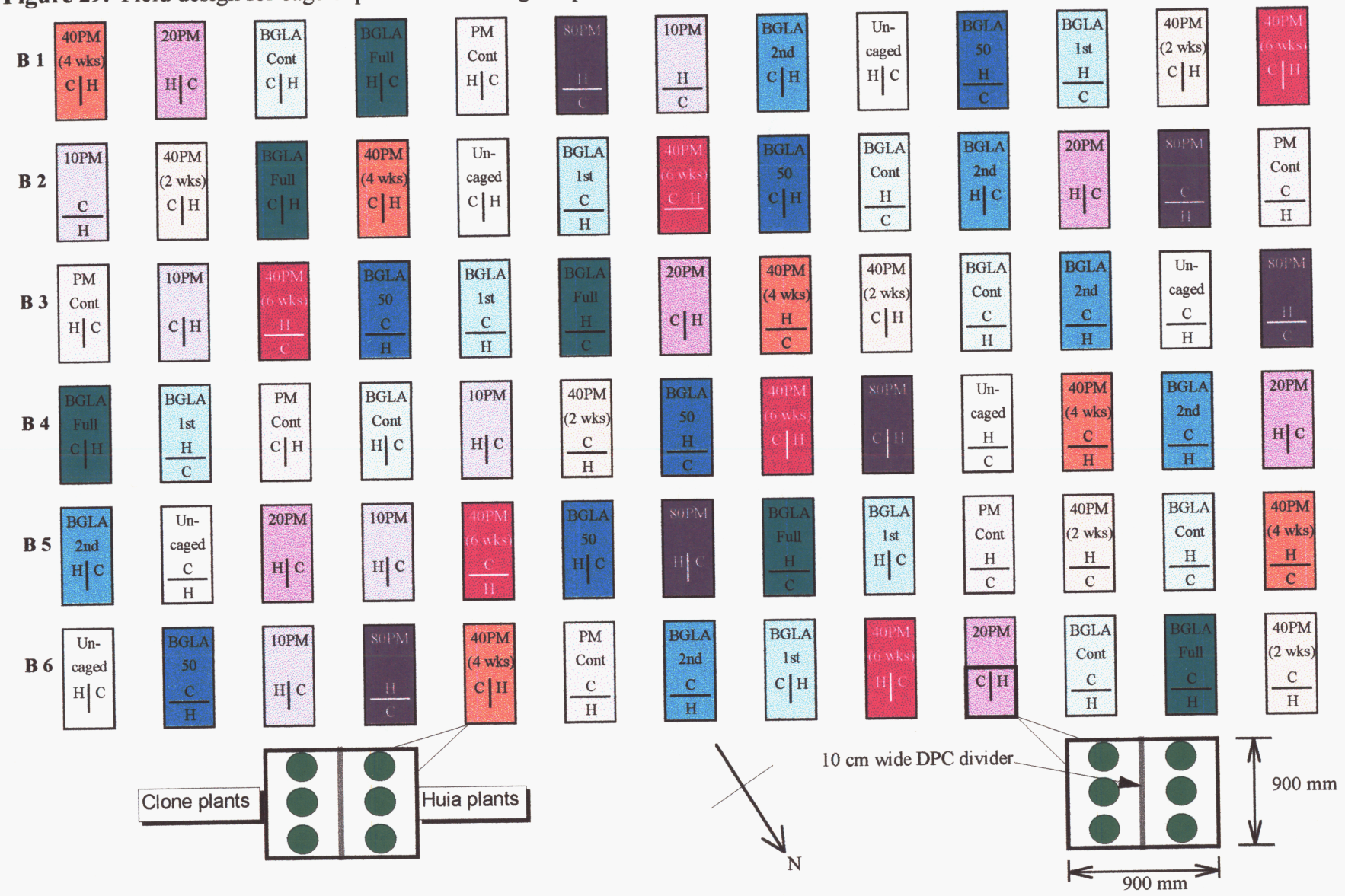
There were 13 treatments replicated six times in a completely randomised block design (Figure 29, Plate 8). The design was generated by randomisation of the column (13 treatments) by row (6 replicates). The treatments can be grouped into three distinct subgroups (Plate 10) to investigate the following:

1. The effect of cages on plant growth and seed yields (hereafter referred to as 'Cage Effect').
2. The impact of several intensities of potato mirids on plant growth and seed yields (hereafter referred to as 'PM Density Impact').
3. The impact of BGLA on plant growth and seed yields at different plant developmental stages (hereafter referred to as 'BGLA Impact').

Plate 9. General view of experiment; 6 rows each with 13 treatment plots.

Plate 10. Three plot types: uncaged (foreground), potato mirid coarse-mesh isolation cages (black), bluegreen lucerne aphid fine-mesh isolation cages (white) used in the experiment.

Figure 29. Field design for cage experiment showing the position of each treatment by block (B1-6) and planting alignment.



Cage Effect

The effect of the two cage types on plant growth and seed yields was measured against an uncaged plot (Plate 10). The caged plots were also used as the control plots for each insect species studied. All three treatments were kept insect-free by several applications of insecticide during the season (refer Table 19).

PM Density Impact

There were five PM treatments covering a range of densities (0, 10, 20, 40 and 80) per cage. Second and third instar PM nymphs were collected from a nearby white clover crop, field borders, and from a 'Huia' white clover crop at Tai Tapu using a sweep net. Uninjured nymphs were placed into aerated containers in cage lots and transferred to the cages within two hours of collection during 16-18 November.

All cages were suction sampled to collect survivors on 2 January (six weeks after infestation). Some second generation nymphs were collected (refer to 'N' columns Table 26). Numbers of both adult and nymphs were recorded for the two plant types per cage. Fluvalinate was applied to all cages (Table 19) later on the same day.

PM 40 Time Impact

Two additional cages per block were infested with 40 PM nymphs at the same time as the 'PM density' treatments to determine the effect of the cages on PM survival (Figure 29). One of the cages was suction sampled after two weeks on 3 December (PM 40(2 wks)) the other after four weeks on 18 December (PM 40(4 wks)) and a third cage (PM 40(6 wks)), which was part of the 'PM density' treatments that was suction sampled after six weeks (when all the 'PM density' plots were sampled) to recover surviving PM. The cages were sprayed with insecticide soon after PM removal on their respective dates (refer Table 19).

BGLA Impact

There were five BGLA cage treatments in the experiment (Table 18). A control cage that was kept aphid-free by regular insecticide spray applications (Table 19), three separate plant developmental

stages infested with 200 BGLA/plant for two weeks and a further treatment infested with 50 winged BGLA/cage and left to build up over several plant developmental stages. As such aphids were applied 'early' (14 November) and sprayed out 'late' (19 December). A separate cage was used for each treatment.

The BGLA stock colony was reared on potted 'Huia' plants at room temperature in the laboratory. The laboratory colonies were caged within a fine mesh to prevent contamination by aphid parasitoids and predators. They remained free of natural enemies throughout the season.

Table 18. BGLA treatments and infestation management.

Developmental Stage	Infestation	Date Introduced	Suction Sampled
Control	None		None
1st inflorescence	200/plant	14 Nov	28 Nov
2nd inflorescence	200/plant	4 Dec	18 Dec
Full inflorescence	200/plant	19 Dec	2 Jan
Early-late infestation	50/cage	14 Nov	18 Dec

The cages were suction sampled two weeks (or five weeks in the 'Early-late infestation') after they had been infested using a two-stroke Stihl (BG72) motor mounted on a collection container (similar to that described by Arnold 1994) covering a suction area of 201 cm^2. The number of BGLA collected from the clonal and 'Huia' plants was recorded separately. The 'Early-late infestation' plots were sampled and sprayed two weeks earlier (19 December) than expected due to the high numbers of BGLA that had built up over the period (Plate 11). If left untreated the aphids would have killed the plants within a 2-3 weeks. The fungal disease *Entomophthora* spp. had also infected and killed large numbers of BGLA in the 'Early-late infestation' plots (Plate 23, Chapter 6). *Entomophthora* was first seen in cages a week before sampling and spraying the 'Early-late infestation' plots.

All cages were removed from the plots on 31 January to expose the plants to natural conditions for seed set. This had the effect of opening up the plant canopy to allow good penetration of applied herbicides.

Plate 11. The bluegreen lucerne numbers in the 'Early-late infestation' treatments were so high that they were sprayed earlier (19 December) than expected to save the plants.

Spray Regime

Dichlorvos (1000 g/litre dichlorvos, Nufarm) at 0.8 ml/litre water was applied over all plots on 12 November to kill resident insects before the introduction of PM nymphs and BGLA (Table 19). The plants were tested for residues by placing 20 BGLA in clip cages on plants during the morning of 13 November. No aphid mortalities were recorded when the caged BGLA were checked at 3.30 p.m., indicating that chemical residues were not toxic. The spray was applied with a Knapsack sprayer equipped with a Teejet® 8002VB spray nozzle.

Table 19. Insecticide spray programme for the different treatments during the field cage experiment.

Treatment	Spray Applications						
	12/11 (D)[8]	13/11 (D)	29/11 (D)	12/12 (D)	13/12 (M)	19/12 (K)	2/1 (M)
PM 0	✓	✓	✓	✓	✓	✓	✓
PM 10	✓	✓	✓				✓
PM 20	✓	✓	✓				✓
PM 40(2wks)	✓	✓	✓	✓	✓	✓	✓
PM 40(4wks)	✓	✓	✓			✓	✓
PM 40(6wks)	✓	✓	✓				✓
PM 80	✓	✓	✓				✓
0 BGLA	✓	✓	✓	✓	✓	✓	✓
1st BGLA	✓		✓	✓	✓		✓
2nd BGLA	✓	✓	✓			✓	✓
Full BGLA	✓	✓	✓				✓
Early-late infestation	✓					✓	✓

The amounts of insecticide applied per plot were approximately: dichlorvos 0.08 g a.i./m^2 (800 g a.i./ha); fluvalinate 0.01 g a.i./m^2 (100 g a.i./ha); and lambda-cyhalothrin at 0.005 g a.i./m^2 (50 g a.i./ha).

Pollination

A honey bee (*Apis mellifera* L.) hive was located approximately 50 m away from the experimental area. Honey bees were seen actively foraging along with *Bombus terrestris* (L.) workers on the uncaged plots and inside cages later in the season when the lids were removed. *B. terrestris* workers were collected from the Lincoln University orchard for the first three weeks of the season and thereafter were obtained from laboratory-reared colonies. The cages were checked every 4-5 days and, if required, replenished with one or two bumble bees. One bumble bee per cage gave excellent pollination and seed set in previous cage experiments (Pearson 1991; Schroeder 1995).

[8] (D)= 'Dichlorvos 100E' (1000 g/l dichlorvos, Nufarm) 0.8 ml/litre water. (M)= 'Mavrik Aquaflow' (240 g/l fluvalinate, Yates N.Z. Ltd.) 0.5 ml/litre water. (K)= 'Karate' (50 g/litre lambda-cyhalothrin, Crop Care N.Z. Ltd.) 1ml/litre water

Inflorescence Numbers and Damage Assessment

Weekly inflorescence counts were taken for each plot. Only inflorescences that had florets available for pollination were counted. Inflorescences of the same age that showed symptoms of feeding injury (Plate 13) were also counted. The same inflorescence damage criteria were used for both PM and BGLA infested plots. The percentages of damaged inflorescences ('% damaged') were recorded at each date. An inflorescence count for each plant type was taken for each plot during the first 7 weeks (18 November to 2 January), thereafter counts were taken until 24 January for the whole cage as it was hard to distinguish between the clone and 'Huia' plants.

Plate 13. Early inflorescence potato mirid feeding injury. The bud has been destroyed and will senesce prematurely.

Plate 14. Damage caused by potato mirid feeding to a later developing inflorescence. The lower florets have not been affected and will produce seed, while the apical florets have been destroyed and will senesce prematurely.

Harvest and Assessment

All plots were sprayed with 'MCPA' (375 g/litre MCPA, Dow Agrosciences) at 3.75 g a.i./litre with 12 ml 'Superstick' (100% non-ionic surfactants, Yates N.Z. Ltd.) in 6 litres of water on 11 February to suppress plant growth and open up the sward for good penetration of the following desiccant application. All plots were sprayed with a desiccant herbicide ('Reglone', 200 g/litre diquat, Crop Care N.Z. Ltd.) at 2.0 g a.i./litre with 12 ml 'Superstick' in 19 litres of water on 24 February.

All the plots were harvested on 3-4 March using electric hand shears, similar to portable sheep shears. Clonal and 'Huia' plants were placed in separate paper bags, which were then placed in drying ovens at 80^0C for several days until completely dry.

The harvested samples were weighed for dry matter and threshed for seed using a belt thresher. The resultant seed and debris were dressed using an air screen separator to remove the debris and light seed. The seed samples were then dressed by a 'Seedburo' vertical air-draft separator set at two levels for first (thousand seed weight above 0.6 g) and second (thousand seed weight between 0.54 to 0.6 g) quality seed (consistent with commercial operations). For each treatment, thousand seed weights (TSW) were determined by taking the average of three, 200-seed sample weights and multiplying by five. The seed was counted by a 'Seedburo 801 Count-A-Pak' apparatus set at a sensitivity of 0.2 and vibration speed of 60. First and second quality, total and thousand seed weights were recorded for each plant type per plot.

Analysis of Results

Data were analysed using the Genstat® for Windows statistical package (© Lawes Agricultural Trust, IACR, Rothamsted, U.K.). Because of the row-column experimental design it was assumed that there would be a common variance between the three experimental groups (controls, BGLA and PM). This assumption held true for the seed yield components, but not for the flowering components (inflorescences and % damaged inflorescences). To compensate for the significant difference in variance between groups, data from each group were analysed separately. The data were initially analysed using the residual error maximum likelihood (REML) model, but comparisons with the standard analysis of variance gave similar results. General analysis of variance results are presented using the $LSD_{0.05}$ test to separate means.

RESULTS

The following results have been grouped into their respective sections so that comparisons between treatments can be easily interpreted from one study component to the next (e.g., the effect of inflorescence damage on resultant seed yield).

Cage Effect

Inflorescence Numbers and Damage Assessment

For numbers of inflorescences and proportions of damaged inflorescences (% damaged) there are two sets of data. The first set evaluates the effect of plant type from 18 November to 2 January,

whereas the second set evaluates the effect of treatment for the whole cage (i.e., 'Huia' and clone plants combined) from week 18 November to 24 January. The two sets originated because it was not possible after week 7 to distinguish which inflorescences belonged to each plant type because of vigorous growth within the plots. 'Total inflorescences' refers to the sum of inflorescences for each sampling time.

Plant type effect (18 November to 2 January)

Overall impact of all treatments

Up to 9 December there were no significant (P> 0.05) differences in inflorescence numbers between the 'Huia' and clone plants in all plots. From 9 December onwards, the clone plants had significantly fewer inflorescences than the 'Huia' plants (Table 20). The mean total inflorescences over the seven weeks were 298.6 for clone plants and 360.1 for 'Huia' plants.

Table 20. Overall white clover inflorescences and % damaged inflorescences for clone and 'Huia' plants from all treatment plots (18 November 1996 to 2 January 1997).

Plant Type	Dates sampled 18-Nov	25-Nov	2-Dec	9-Dec	16-Dec	23-Dec	2-Jan
			Inflorescence Numbers/ Cage				
Clone	11.4	26.0	39.4	43.6	48.2	52.8	77.2
'Huia'	12.6	26.7	40.0	46.8*	62.7***	80.4***	90.9***
$LSD_{0.05}$	1.2	2.2	2.7	3.0	3.9	5.0	4.9
			% Damaged Inflorescences				
Clone	8.5	21.3***	34.8**	34.3*	31.0	24.0	11.7*
'Huia'	13.6**	15.8	29.8	32.1	29.2	24.0	10.0
$LSD_{0.05}$	3.3	2.7	3.4	1.9	2.3	2.7	1.3

Significantly higher at * P< 0.05, ** P< 0.01 and *** P< 0.001 levels.

The proportion of damaged inflorescences (% damaged) over the seven weeks varied between the clone and 'Huia' plants (Table 20). However, there was no significant (P> 0.05) difference between the mean proportion of inflorescence damage in the 'Huia' (22.1%) compared with the clonal plants (23.6%, $LSD_{0.05}$ 2.0).

There were no significant (P> 0.05) differences between clone and 'Huia' inflorescences or % damaged inflorescences in the uncaged and control cages (0 BGLA and PM 0) during the seven weeks.

Effect of treatment (18 November to 24 January)

There were few sampling dates on which there was a significant difference in inflorescence numbers and percentage damaged inflorescences between control cage and uncaged plots (Table 21). Overall, the proportion of damage was, however, low and never surpassed 15.2% inflorescence damage (PM 0 on 18 November) per plot.

Table 21. The effect of the two cage types on white clover inflorescences and % damaged inflorescences compared with the uncaged plots over the season (18 November 1996 to 24 January 1997).

Treatment	Date sampled 18-Nov	25-Nov	2-Dec	9-Dec	16-Dec	23-Dec	2-Jan	10-Jan	16-Jan	24-Jan
					Inflorescence Numbers/ Cage					
Uncaged	32.7	67.5	79.3	96	136.0	164.8	169.7	97.5	66.3	24.3
0 BGLA	25.8	54.5	82.8	105.5	135.3	164.2	183.8	92.3	70.8	27.3
PM 0	19.0	55.2	91.8	112.3	130.0	125.8	181.7	103.0	82.0	38.3
$LSD_{0.05}$	8.9*	17.4	14.2	22.6	31.8	40.4	34.5	20.6	17.1	6.0***
					% Damaged Inflorescences					
Uncaged	9.2	3.7	3.2	1.3	2.5	2.0	4.7	4.7	4.0	13.5
0 BGLA	11.2	7.3	2.3	1.2	2.3	2.0	3.2	9.0	9.0	14.5
PM 0	15.2	7.7	5.3	3.8	4.3	4.5	3.2	5.0	7.2	12.8
$LSD_{0.05}$	9.5	3.7	1.8*	1.2***	2.1	4.1	3.2	3.8	3.3*	10.8

Significant differences derived from ANOVA between the control cage treatments at * P< 0.05, ** P< 0.01, and *** P< 0.001.

Harvest and Assessment

Overall impact of all treatments

'Huia' plants yielded significantly (P< 0.001) more dry matter, first and second quality, total and thousand seed weights than clone plants (Table 22).

Table 22. Yield components collected from clone and 'Huia' white clover plants.

Plant Type	Yield Components (g/Cage) Dry Weight	1st Quality	2nd Quality	Total Yield	1st Quality TSW
Clone	202	14.1	4.0	18.0	0.621
'Huia'	423	20.4	5.8	26.2	0.683
$LSD_{0.05}$	17***	1.7***	0.8***	1.9***	0.025***

*** significant (P< 0.001) differences between plant types.

Although there were no significant (P> 0.05) differences in inflorescences between the three control plots, the uncaged plots significantly (P< 0.001) out-yielded both the caged BGLA and PM plots for all yield components except thousand seed weight and dry weight (Table 23).

Table 23. Yield components for white clover collected from the uncaged and control BGLA and PM cages.

Treatment	Yield Components (g/Cage)				
	Dry Weight	1st Quality	2nd Quality	Total Yield	1st Quality TSW
Uncaged	765	79.4	25.7	105.1	0.679
0 BGLA	719	31.6	8.4	40.0	0.661
PM 0	624	41.8	12.6	54.4	0.672
$LSD_{0.05}$	115	13***	3.8***	13.4***	0.022

Significant differences derived from ANOVA between treatments at *** P< 0.001.

There were also significant (P< 0.05) differences in yields between the BGLA and PM control cages, although the PM plot yields were higher for all components except dry weight.

PM Density and PM 40 Time Impact

Inflorescence Numbers and Damage Assessment

Plant type effect (18 November to 2 January)

There were no significant (P> 0.05) differences between clone and 'Huia' inflorescence numbers in the PM-treated plots. There were, however, significant (P< 0.05) differences in the proportion of damaged inflorescences between clone and 'Huia' plants over the seven weeks. Significantly (P< 0.05) higher damage was recorded on the clone plants on 25 November, 2 December and 2 January and 'Huia' plants on 16 and 23 December, thus indicating no clear trend in inflorescence damage between plant types in the different PM treatments.

Effect of treatment (18 November to 24 January)

Overall, inflorescences decreased with increasing PM density and infestation period. This decrease in inflorescences corresponded to an increase in the proportion of damaged inflorescences (% damaged) (Table 24). Peak flowering occurred after 7 weeks (2 January) in all plots.

PM density impact

PM density had a significant impact on inflorescence numbers between 2 December and 2 January after the introduction of insects to the cages (Table 24). Overall, the largest decrease in inflorescences occurred in the 'PM 80' treatment with a mean of 107 inflorescences/plot compared with 182 inflorescences in the control plots at peak flowering.

Table 24. The effect of the different PM treatments on inflorescences and % damaged inflorescences over the season (18 November 1996 to 24 January 1997).

	Dates sampled									
Treatment	**18-Nov**	**25-Nov**	**2-Dec**	**9-Dec**	**16-Dec**	**23-Dec**	**2-Jan**	**10-Jan**	**16-Jan**	**24-Jan**
					Inflorescence Numbers/ Cage					
PM 0	19.0	55.2	91.8	112.3	130.0	136.7	181.7	103.0	82.0	38.3
PM 10	18.0	43.8	75.2	77.8	110.3	125.8	152.8	107.7	95.2	57.3
PM 20	24.2	52.5	73.0	79.5	91.8	121.0	143.8	121.0	91.2	41.0
PM 40(2wks)	19.8	44.8	63.3	63.3	88.7	131.8	195.7	99.8	86.7	47.30
PM 40(4wks)	20.7	44.7	72.5	71.8	82.0	126.3	218.3	111.8	95.3	41.7
PM 40(6wks)	25.2	50.5	79.7	81.7	85.0	106.2	126.3	98.5	90.0	46.0
PM 80	22.0	41.8	56.3	60.7	59.2	77.0	107.3	87.0	88.0	59.5
$LSD_{0.05}$	6.8	14.7	15.1**	21.4***	26.0***	29.1**	33.0***	21.6	14.1	15.3
					% Damaged Inflorescences					
PM 0	15.2	7.7	5.3	3.8	4.3	4.5	3.2	5.0	7.2	12.8
PM 10	19.8	15.3	33.2	40.0	37.7	14.0	6.3	6.5	5.5	8.3
PM 20	12.2	19.3	49.7	63.5	54.0	35.3	9.3	7.7	9.0	8.7
PM 40(2wks)	13.7	36.5	72.7	74.5	53.5	23.5	6.3	5.5	5.67	8.2
PM 40(4wks)	16.0	34.8	71.0	76.0	57.2	37.2	9.5	5.5	5.83	12.7
PM 40(6wks)	6.2	32.7	80.8	74.2	73.5	65.7	22.8	10.7	10.67	8.8
PM 80	8.7	49.8	89.5	91.8	91.2	81.0	51.2	28.3	7.5	9.3
$LSD_{0.05}$	11.8	12.5***	18.7***	14.1***	16.6***	16.5***	13.1***	10.8***	3.7	3.8

Significant differences from ANOVA between PM treatments at * P< 0.05, ** P< 0.01, and *** P< 0.001.

Inflorescence numbers decreased with increasing PM density and were significantly different for 8 weeks (10 January), which was a week before PM removal from the plots on 16 January (Figure 30a).

The proportion of damaged inflorescences increased with increasing PM density at each of the sampling dates (Table 24 and Figure 30b). The highest proportion (91.8%) occurred in the PM 80 plots at four weeks after the mirids were introduced. The period over which significant inflorescence damage occurred also increased with increasing PM density (Figure 30b). Feeding injury was so intense in the PM 80 plots that inflorescence petioles wilted (Plate 14).

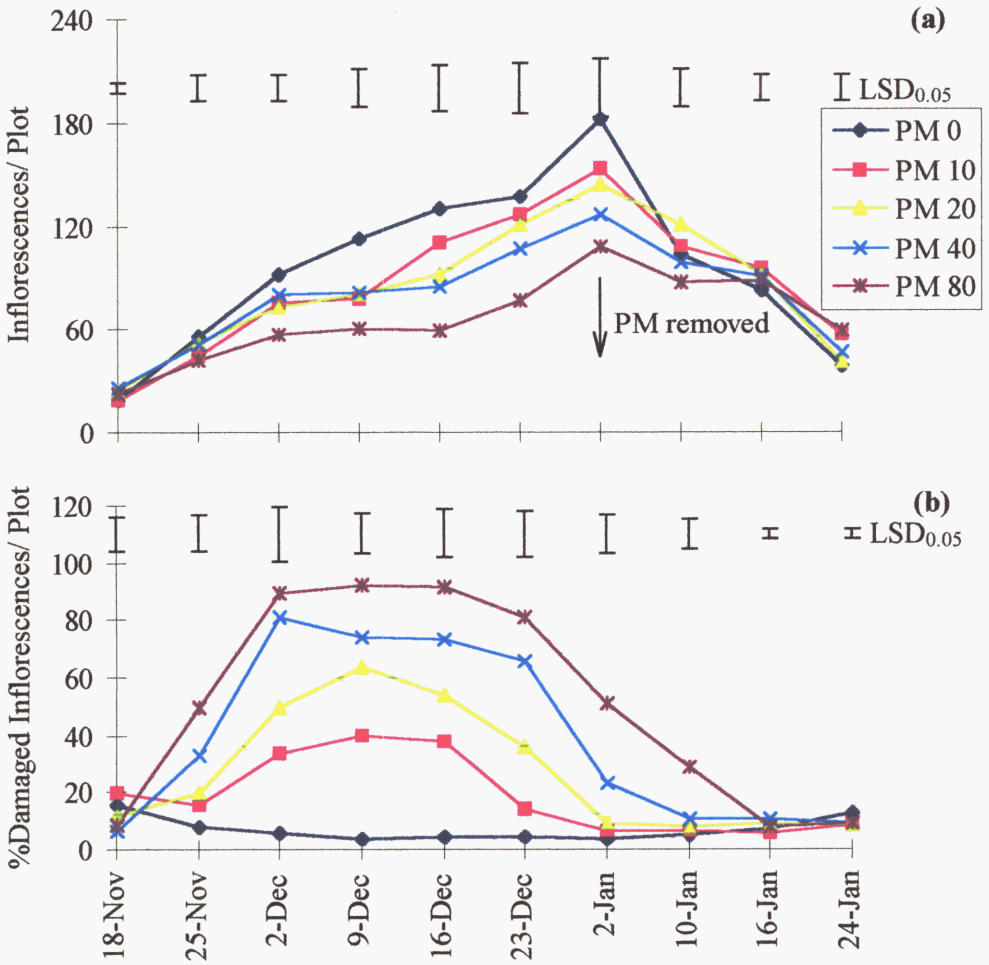


Figure 30. **(a)** Weekly white clover inflorescences from the different PM density plots. **(b)** Weekly % damaged white clover inflorescences from the different PM density plots.

Plate 14. Symptoms of PM injury in the 'PM 80' cages.

PM 40 time impact

Inflorescence numbers peaked on approximately 2 January in all plots. The highest inflorescence peak flowering occurred in the 'PM 40(4 wks)' treatment at 196 (37 inflorescences higher than in the control plot) compared with 107 inflorescences per plot (PM 40(6 wks)) (Table 24). Only the 'PM 40(6 wks)' plots had significantly ($P < 0.001$) lower numbers of inflorescences at peak flowering (2 January) compared with the control plot (Figure 31a).

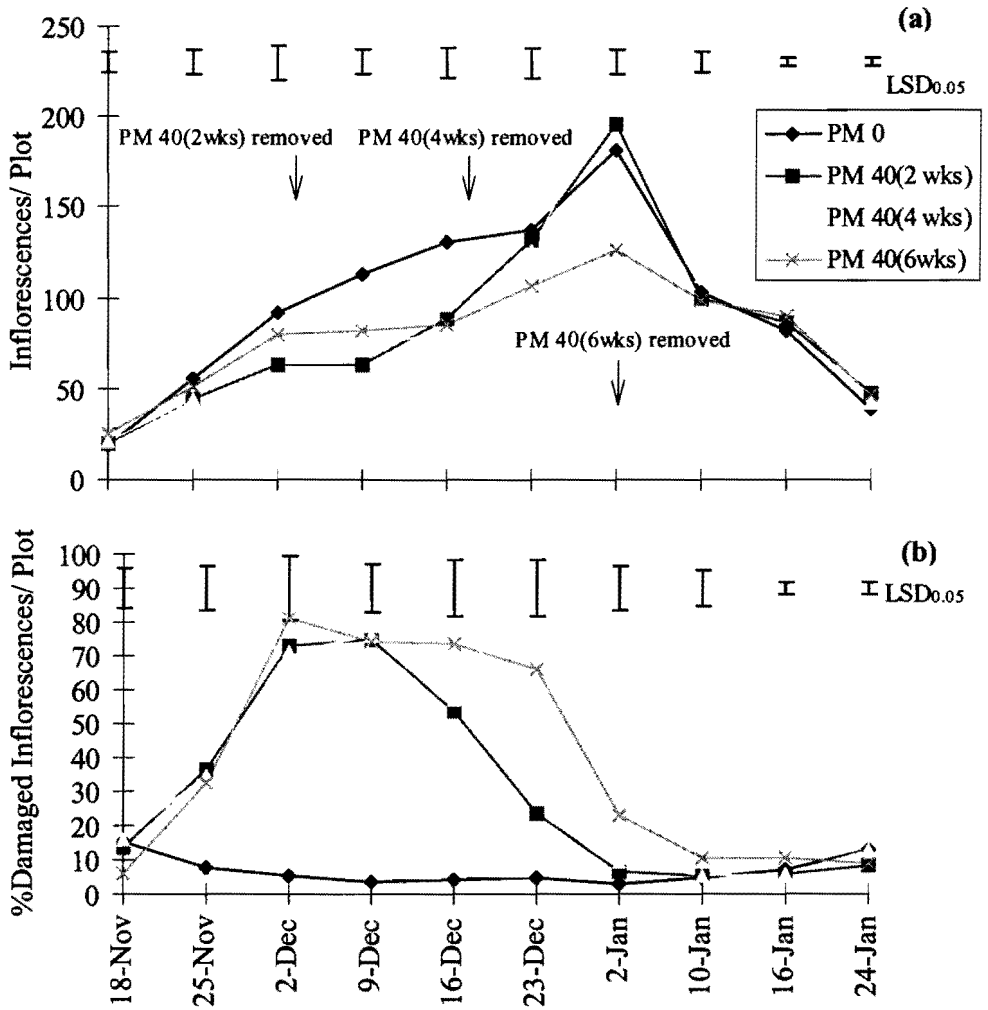


Figure 31. **(a)** Weekly white clover inflorescences from the different PM 40 plots. **(b)** Weekly % damaged white clover inflorescences counted from the different PM 40 plots. Duration of each treatment and peak flowering is shown.

Of the available inflorescences, 'PM 40(6 wks)' had the highest proportion of damaged inflorescences, compared with the other treatments (Figure 31b). The highest proportion of damaged inflorescences (81%) occurred on 2 December in this treatment and the period over which inflorescence damage occurred was greater. The period that inflorescence damage occurred

was similar in the 'PM 40 (2 and 4 wks)' treatments. Inflorescence damage declined towards peak flowering on 2 January and was not significantly (P> 0.05) different in the PM 40 plots compared with the control plots, thereafter.

Harvest and Assessment

PM density impact

PM treatments had no clear effect on the clover plant dry weights. The lowest dry weight came from the 'PM 10' plots, while the highest was collected from the 'PM 40(4 wks)' plots (Table 25). There were significant (P< 0.05, 0.01, 0.001, 0.05) differences in first and second quality, total seed and thousand seed weight yields (respectively) between PM treatments (Table 25). There were significant (P< 0.01, 0.05, 0.01) linear relationships between increasing PM density and first, second and total seed yields (respectively) (see Figure 32). There was an increase in thousand seed weight from 'PM 10' to 'PM 40(6 wks)', but this declined at 'PM 80'. Thousand seed weights were significantly (P< 0.05) lower in the 'PM 10' and '80' treatments compared with the control 'PM 0' treatment (Table 25).

Table 25. Yield components of white clover collected from the different PM treatments.

		Yield Components/ Cage			
Treatment	**Dry Weight**	**1st Quality**	**2nd Quality**	**Total Yield**	**1st Quality TSW**
PM 0	624	41.8	12.6	54.4	0.672
PM 10	576	36.6	9.5	46.1	0.636
PM 20	630	32.6	9.1	41.8	0.648
PM 40(2wks)	608	32.8	7.3	40.1	0.675
PM 40(4wks)	647	32.4	7.8	40.2	0.655
PM 40(6wks)	598	28.8	6.8	33.7	0.672
PM 80	590	20.6	5.3	25.9	0.640
$LSD_{0.05}$	52	11.6*	3.0**	13.1**	0.030*

Significant differences derived from ANOVA between the control cage treatments at * P< 0.05, and ** P< 0.01.

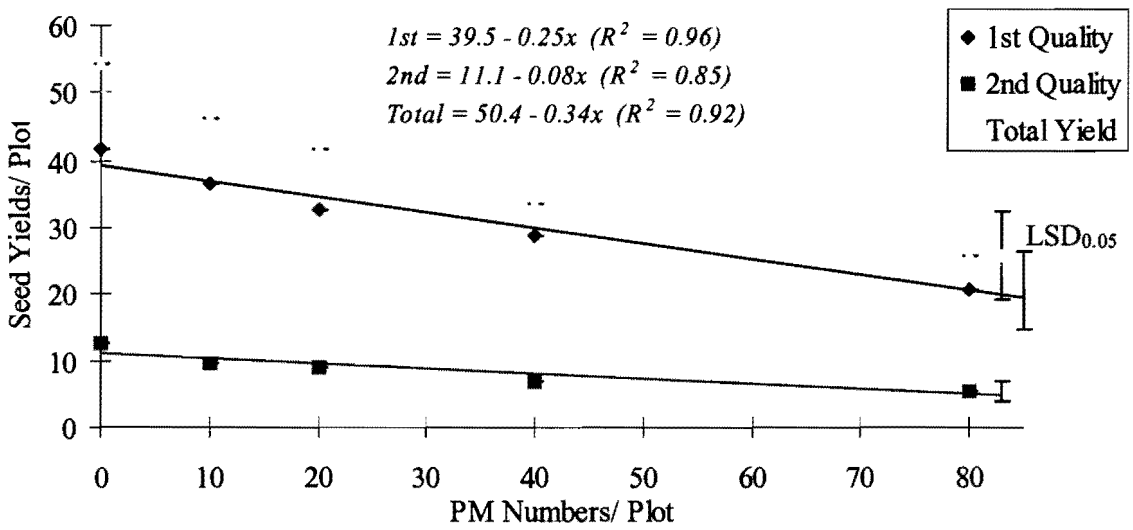


Figure 32. Fitted linear plots and equations for white clover seed yields collected from plots with different PM densities.

PM 40 time impact

There were no significant (P< 0.05) differences between PM 40 treatment means for all the yield components collected (Table 25). The mean total seed yields from both 'PM 40(2 and 4 wks)' were similar (40.1, 40.2 g, respectively), but significantly less than the 'PM 0' treatment (54.4 g), while the 'PM 40(6 wks)' mean total seed yield (33.7 g) was even lower.

PM Cage Survival

PM density impact

All clover in cages were suction sampled for each of the four density treatments (Table 26). The proportion of PM survivors decreased with increasing PM density. The range of PM numbers recovered varied widely (e.g., 1-19 adults 'PM 40(6 wks)'). The appearance of early instars in some samples indicated a second generation had commenced.

Table 26. Mean number of PM (A= adult, N= nymph) recovered from white clover from each cage by suction sampling (applied 16-18 November).

	Treatment											
	PM 10		PM 20		PM 40(2wks)		PM 40(4wks)		PM 40(6wks)		PM 80	
Variable	**A**	**N**	**A**	**N**	**A**	**N**	**A**	**N**	**A**	**N**	**A**	**N**
Clone					3.2	7.8						
'Huia'					6.2	8.5						
Totals	1.7	4.2	5.2	2.0	9.4	16.3	13.8	1.3	8.3	4.0	10.3	1.3
Range	1-4	1-7	2-10	0-5	4-14	11-23	3-19	0-4	1-19	1-13	4-16	0-3
%Recover	59%		36%		64%		38%		31%		15%	
Sampled	2 Jan		2 Jan		3 Dec		18 Dec		2 Jan		2 Jan	

When the percentage recovery (% Recovered) of PM densities was regressed against total seed yields a nearly significant (P= 0.06) positive relationship was found (Figure 33).

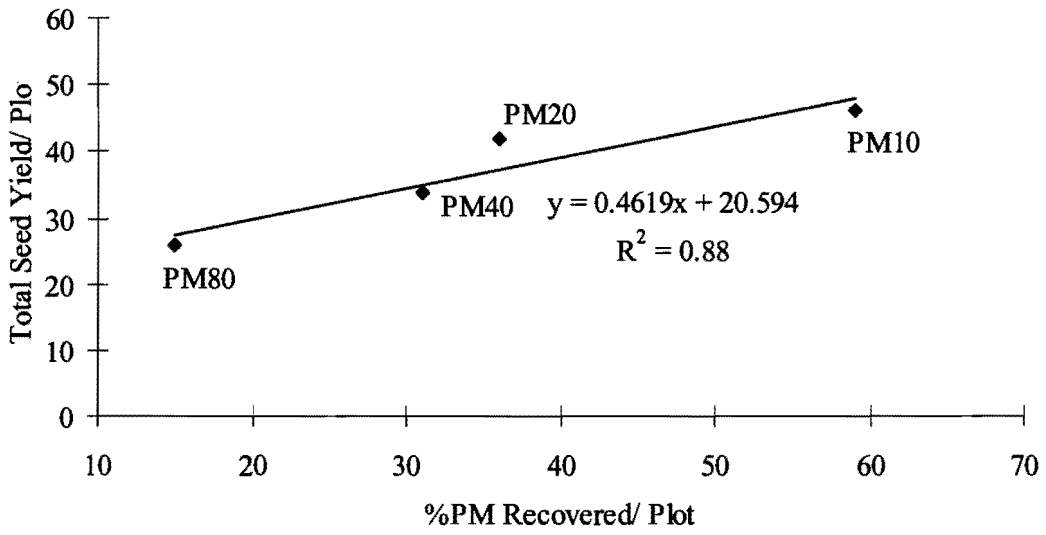


Figure 33. Fitted linear plot (and equation) of total white clover seed yields collected by %PM recovered from the different PM density treatments.

PM 40 time impact

Suction samples were taken from the whole cage except for the 'PM 40(2 wks)' treatment where individual plant types were sampled (Table 26). There were twice as many adults recovered from the 'PM 40(2 wks)' 'Huia' plants than from clone plants, but there was little difference in the numbers of PM nymphs recovered from each plant type. % Recovery of PM decreased with time from 'PM 40(2 wks)' to 'PM 40(6 wks)' However, the number of PM nymphs increased from

1.3/cage ('PM 40(4 wks)') to 4/cage ('PM 40(6 wks)') indicating the emergence of a second generation within the 'PM 40(6 wks)' treatment.

Inflorescence and Seed Yield Interactions

There was a significant ($P < 0.001$) positive linear interaction between total inflorescence and resultant seed yields with decreasing PM densities (Figure 34).

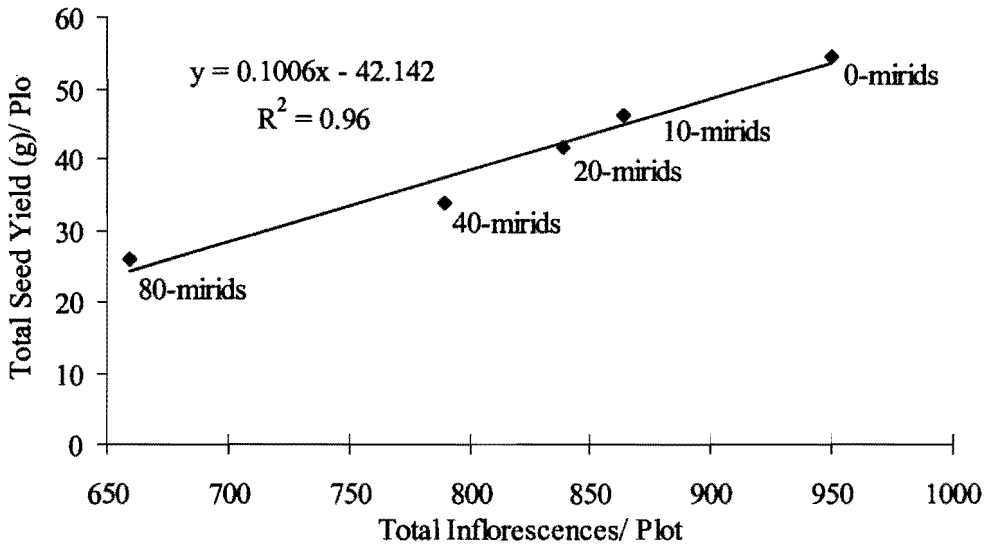


Figure 34. Fitted linear plot (and equation) of total white clover seed yields harvested against total inflorescences counted from the different PM density treatments.

BGLA Impact

Inflorescence Numbers and Damage Assessment

Plant type effect (18 November to 2 January)

There were no significant (P> 0.05) differences between clone and 'Huia' inflorescences, or % damaged inflorescences in the different BGLA treatments during the seven weeks.

Effect of treatment (18 November to 24 January)

Inflorescence numbers reached their maximum after 6 weeks (2 January) (Table 27). There were significant differences (P< 0.05) in number of inflorescences between the different BGLA treatments after 2, 6, and 8 weeks (Table 27 and Figure 35a). The largest overall reduction in inflorescences occurred in the 'Early-late infested' and 'Full BGLA' plots.

Table 27. The effect of the different BGLA treatments on white clover inflorescences and % damaged inflorescences over the season (18 November 1996 to 24 January 1997).

Treatment	Date sampled									
	18-Nov	25-Nov	2-Dec	9-Dec	16-Dec	23-Dec	2-Jan	10-Jan	16-Jan	24-Jan
	Inflorescence Numbers/ Cage									
0 BGLA	25.8	54.5	82.8	105.5	135.3	164.2	183.8	92.3	70.8	27.3
1st BGLA	21.7	50.0	83.0	113.5	134.5	169.0	173.5	85.8	66.3	34.2
2nd BGLA	27.0	66.2	96.5	117.2	149.8	144.2	213.5	101.7	70.2	29.3
Full BGLA	25.5	52.2	86.8	99.8	131.0	160.2	152.3	64.0	49.7	32.2
Early-late infestation	29.7	61.3	90.5	95.5	111.3	104.3	166.7	91.5	76.2	41.8
$LSD_{0.05}$	8.2	11.4*	24.2	24.8	29.7	36.6**	46.7	24.6*	22.3	15.6
	% Damaged Inflorescences									
0 BGLA	11.2	7.3	2.3	1.2	2.3	2.0	3.2	9.0	9.0	14.5
1st BGLA	8.0	9.5	2.5	1.5	2.5	4.5	5.8	6.7	8.0	8.2
2nd BGLA	8.3	6.0	2.3	1.2	2.2	2.8	3.0	7.5	13.3	19.2
Full BGLA	12.5	8.2	2.5	0.8	2.8	2.0	4.0	32.8	13.3	10.3
Early-late infestation	8.8	9.7	5.2	1.5	4.7	31.3	7.8	8.3	10.1	12.3
$LSD_{0.05}$	7.1	3.5	3.1	0.7	2.0	14.3***	2.6**	13.3**	6.4	7.7

Significant differences from ANOVA between BGLA treatments at * P< 0.05, ** P< 0.01, and *** P< 0.001.

Of these differences the most significant (P< 0.01) occurred after 6 weeks when the 'Early-late infestation' plots had lower inflorescence numbers (104.3/plot) compared with the other plots (e.g., control at 164.2/plot). Inflorescence numbers appeared to increase gradually once the aphids from

the 'Early-late infestation' treatment were removed by spraying on 19 December. In contrast, where BGLA were removed later (2 January) in the 'Full BGLA' treatment, a reduction in inflorescence number to 152/plot instead of a peak on 2 January occurred.

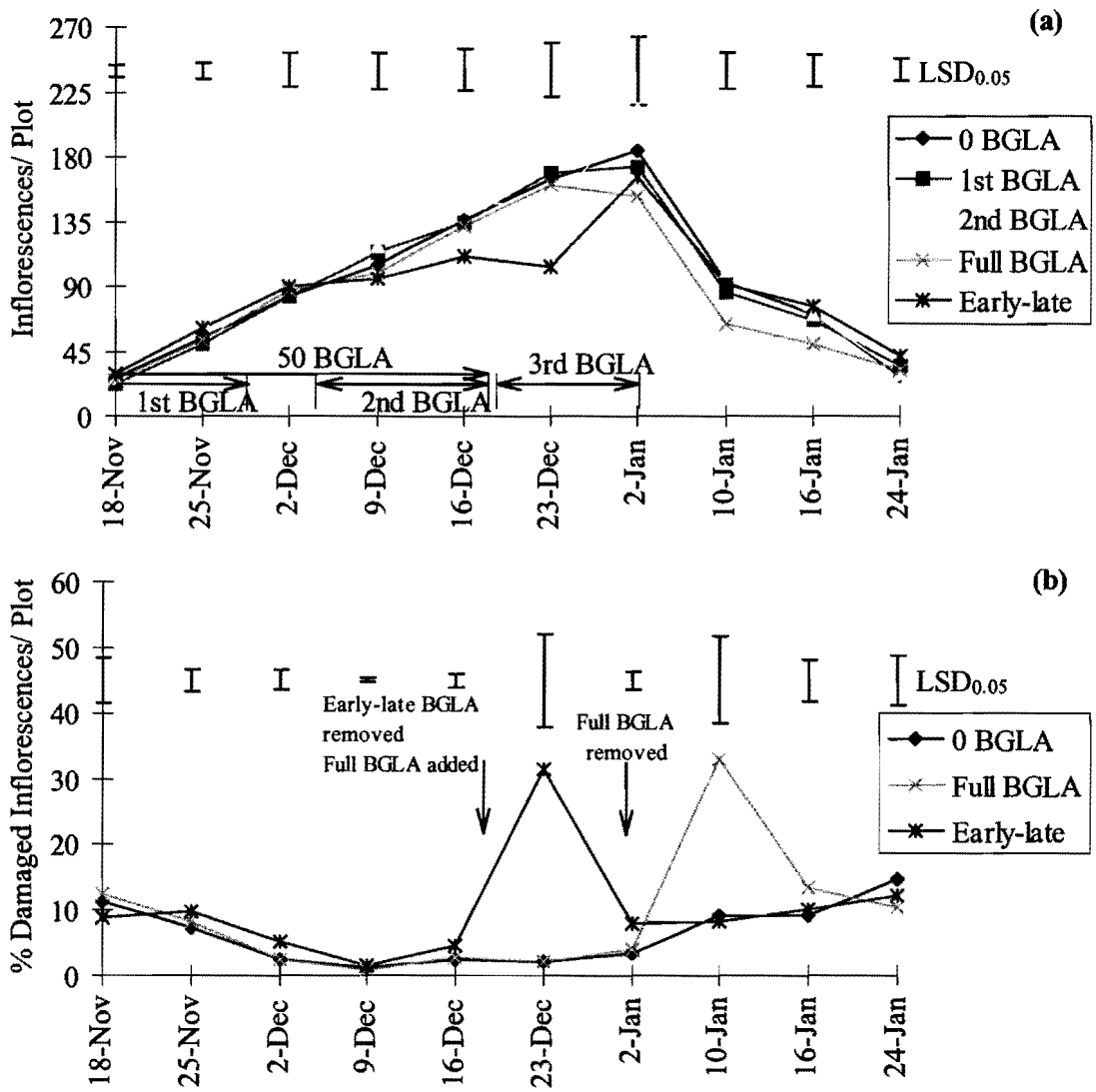


Figure 35. (a) Weekly inflorescences from the different BGLA plots. Duration of each treatment is shown. **(b)** Weekly % damaged inflorescences from the '0, Full and Early-late infestation' BGLA plots.

There were significantly ($P< 0.001$) higher proportions of damaged inflorescences in the 'Early-late infestation' treatment after the sixth week (Table 27 or 23 December, Figure 35b). This peak of inflorescence damage occurred within five days of BGLA removal from the 'Early-late infestation' plots and rapidly decreased thereafter. A similar result occurred in the 'Full BGLA' plots which recorded significantly ($P< 0.01$) higher proportions of inflorescence damage after week eight (Table 27 or 10 January, Figure 35b) compared with the control plots.

Harvest and Assessment

There were no significant differences in first, second and total seed yields between BGLA treatments (Table 28). The harvested first and total plot seed yields decreased from '0 BGLA' and were lowest in the 'Full BGLA' treatment. The dry weights and first quality thousand seed weights were significantly ($P< 0.001$) lower in the 'Full' and 'Early-late infestation' treatment compared with the '0 BGLA' plots (Table 28).

Table 28. Yield components collected from the different BGLA treatments.

		Yield Components			
Treatment	**Dry Weight**	**1st Quality**	**2nd Quality**	**Total Yield**	**1st Quality TSW**
0 BGLA	719	31.6	8.4	40.0	0.661
1st BGLA	598	30.6	7.7	38.3	0.653
2nd BGLA	719	28.5	9.2	37.6	0.654
Full BGLA	548	22.1	6.9	28.9	0.618
Early-late infestation	543	26.6	8.2	34.8	0.614
$LSD_{0.05}$	87***	8.1	3.4	9.9	0.024***

Significant differences derived from ANOVA between the control cage treatments at *** $P< 0.001$.

BGLA Survival in Cages

Suction samples were taken from the whole cage except for '1st BGLA' plots, where separate samples were taken for each plant type (Table 29). Clone plants for this treatment had more BGLA recovered from them than from 'Huia' plants. There was a decrease in BGLA numbers from infestation to recovery in both '1st' and '2nd BGLA' plots, while greater numbers of BGLA were recovered from the 'Full' and 'Early-late infestation' plots. The highest numbers collected came from the 'Early-late infestation' treatment, which had a 41-fold increase in BGLA numbers from infestation to recovery.

Table 29. Mean number of BGLA recovered by suction sampling from white clover plants grown in cages.

Variables	Treatment				
	1st BGLA		2nd BGLA	Full BGLA	Early-late infestation
	Clone	'Huia'	Whole Cage	Whole Cage	Whole Cage
Applied	600	600	1200	1200	50
Recovered	308	256	538	2827	2082
Range	167-410	210-310	159-1100	1600-3800	1160-6500
%Recovery	51%	43%	45%	236%	4164%
Infested	14 Nov		4 Dec	19 Dec	14 Nov
Sampled	28 Nov		18 Dec	2 Jan	18 Dec

Inflorescence and Seed Yield Interactions

There was a nearly significant (P= 0.052) positive interaction between total inflorescence numbers and total seed yields per treatment (Figure 36). The later the BGLA treatment was applied the greater the impact on total inflorescence number and resultant seed yield decrease.

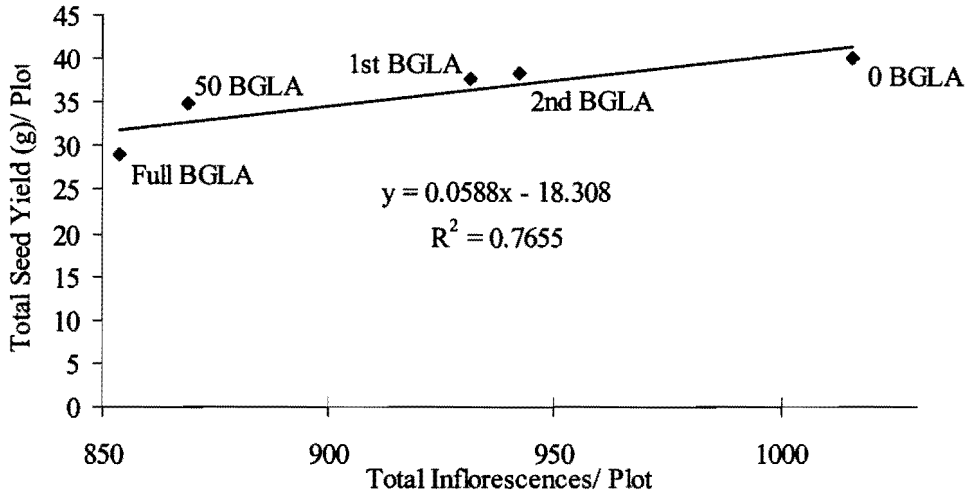


Figure 36. Fitted linear plot (and equation) of total white clover seed yields harvested against total number of inflorescences counted from the different BGLA treatments.

DISCUSSION

Plant management

The 'Huia' plants used in the experiment had more vigorous growth and production throughout the whole experiment compared with the clonal plants. The 'Huia' plants were developed from nucleus seed collected during the 1993-94 cage experiment, while the clonal plants were developed from sections of stolons from high seed-yielding clonal plants. This was the fourth successive year that these plants had been cloned. Long-term cloning like this weakens the plants making them vulnerable to disease and low performance over time (I.J. Baird pers. comm.). Evidence of poor vigour was shown when the percentage ground cover for each plant type was recorded on 23 December. The 'Huia' plants always covered 100% for their half of each plot while the clonal plant coverage ranged between 75 and 95%. The plant type differences in flowering and seed production were also indicators of the cloned plants' poorer performance (Tables 20 & 21). This is best illustrated by the significant ($P< 0.001$) differences in seed quality measured by the thousand seed weights (0.683 g for 'Huia' compared with 0.621 g for the clones). It is, therefore, recommended that clonal material should be selected from plants no greater than two generations from the original parent material (I.J. Baird pers. comm.).

Cage design

Although no parasitoids or predators were observed inside the BGLA cages, they were observed in the PM cages, which had a larger mesh size. Ladybird adults congregated around the flaps of the openings on the PM cages and sometimes fell into the caged area when they were opened. Predators found in a suction sample from the 'PM 40(4 wks)' plot in block 3 included lacewing adults (24) and nymphs (8), ladybird adults (5) and larvae (1), and money spiders (10). Schroeder (1995), however, suggested that these predators were not likely to have much impact on PM as they were considered to be specific aphid feeders. Young PM instars, if any, were likely to be preyed upon. The presence of these predators in the PM cages may have been beneficial in keeping BGLA numbers down. The introduction of adult lacewing (*M. tasmaniae* (Walker)) into similar cages was used as an aphid control tool by Pearson (1991) in a study to determine the feeding effects of Australian crop mirid on white clover inflorescence and seed production. In this study some BGLA were collected from the PM treatments (e.g., 32 BGLA collected in the 'PM 40(4 wks)' block 3 plot).

Experimental design

The treatments were replicated six times (one replicate more than other seasons) in an effort to reduce experimental variability. The column by row randomised design allowed the best block-treatment randomisation for later statistical analysis. Although some shading of cages on other plots occurred early and later in the day, differences between plots were considered to be treatment induced. The design also allowed clear visual comparisons to be made between the three experimental subgroups (controls, BGLA and PM).

Spray regime

Early instar PM nymphs were observed on some clover plants before the plots were caged. The dichlorvos clean-up spray applied before the cages were infested successfully killed these nymphs, which were found dead soon after application. In previous seasons, pyrethrum (14 g/litre pyrethrins a.i., 56.5 g/litre piperonyl butoxide, Yates N.Z. Ltd.) was applied to all cages at 0.7g in 9 litres of water to kill resident insects. Pyrethrum at this rate, however, was not lethal to PM nymphs. Dichlorvos was used because it has both contact and fumigant killing action and low residual activity (Schroeder & Chapman 1995). This low residual activity was confirmed by the nil mortalities of BGLA retained in small clip cages placed on the plants the day following dichlorvos application.

Although the insecticide applications during the season were three to five times higher than recommended field rates (O'Connor 1996) (Table 19), no evidence of spray phytotoxicity was found on any plants. Furthermore, the amounts applied did not achieve higher kill rates, but may have provided a longer period of residual action for fluvalinate and lambda-cyhalothrin.

Weather variables

During the 1993-94 cage experiment using PM cages only the uncaged plots had higher (but not significantly ($P > 0.05$) higher) seed yield components compared with the caged control plots.

Table 30. Comparison of weather variables between the 1993-94, 1996-97 seasons and long-term means.

Weather Variables	Long-term means (1975-91)			Season 1993-94			1996-97		
	Nov	Dec	Jan	Nov	Dec	Jan	Nov	Dec	Jan
Grass level temp (^{0}C)				4.7	7.5	10.0	4.2	6.9	9.0
10 cm soil temp (^{0}C)				13.3	14.6	11.9	14.6	17.5	17.1
Total solar radiation (Lux)	603	673	670	583	620	696	723.5	762	745
Total rainfall (mm)	55.7	61.3	50.3	75.6	99.8	52.4	31.9	48.0	93.7
Mean air temp (^{0}C)	13.1	15.7	17.0	10.9	13.1	16.8	12.3	14.9	14.7

The 1993-94 season was overall much cooler and had less accumulated solar radiation compared with the 1996-97 season (Table 30). Inflorescence density in the uncaged plots were considerably lower during the 1993-94 (67 on 24 December) compared with the 1996-97 season (165 on 23 December, Table 21). This difference in inflorescence numbers contributed to the nearly two-fold increase in total seed yields of 59.4 g in 1993-94 to 105.1 g in 1996-97.

Heavy rainfall occurred on 19 November (12.4 mm) five days after '1st BGLA' infestation, 5 December (13.1 mm) one day after '2nd BGLA' infestation, 14 December (9.9 mm), 30 December (17.3 mm) eleven days after 'Full BGLA' infestation, 4 January (12.9 mm) and 10-11 January (23.7 and 22.7 mm, respectively). Irrigation was applied at 30 mm on 26-27 October and at 20 mm on 14 November (just after 1st BGLA infestation). The effect of these rainfall or irrigation events on BGLA numbers was not evaluated. Heavy rainfalls have been associated with dramatic reductions in aphid populations (Roy 1975; Angood and Stewart 1980), whereas high populations of BGLA observed in the field were associated with high vegetative growth from fields receiving irrigation and good rainfalls.

Impact of Treatments on Inflorescence Number and Damage and Resultant Seed Yield Components

Cage effect

During the 1993-94 season there was no (P> 0.05) difference in the grass-level temperatures between caged PM and uncaged control treatments (Schroeder 1995). While not affecting the clover-level temperature within plots, it is likely that the materials used to cover the cages would have intercepted some incoming solar radiation. However, no measurements were taken to

account for these differences. There was no significant (P> 0.05) difference in inflorescence numbers between the control cages and uncaged plots on 25 November to 16 January (Table 21). However, these inflorescences did not result in the same seed yields (Table 23). The uncaged plots significantly (P< 0.001) out-yielded the two control cages, almost doubling the total seed produced in the 'PM 0' treatment (105.1 compared with 54.4 g, respectively), while the 'PM 0' treatment produced significantly more seed than the 0 BGLA plots (40.0 g). This may be the result of poor pollination, but was more likely to be a cage effect. Thousand seed weight was not affected by the cages.

PM density impact

While high BGLA numbers are likely to have affected the partitioning of assimilates to the developing seed, the effect of increasing PM density was to increase inflorescence mortality (Table 24, Figure 30a) and injury (Table 24, Figure 30b). The loss in inflorescences resulted in loss of seed yield that followed a negative linear trend with increasing PM density (Figure 34). Total seed yields were more than halved in the 'PM 80' (25.9 g) treatment compared with the control 'PM 0' (54.4 g) treatment (Table 25, Figure 32). Potential field losses are given in Table 31, based on the assumption that cage losses would be similar to the field losses.

Table 31. Actual and potential seed losses caused by PM in cages and in the field.

Harvest	**PM Densities/Cage**				
Variables	**0**	**10**	**20**	**40**	**80**
Total/cage (g)	54.4	46.1	41.8	33.7	25.9
g/m²	67.2	56.9	51.6	41.6	32.0
Kg/ha	672	569	516	416	320
Profit (at $4/kg)	$2,688	$2,276	$2,064	$1,664	$1,280
Loss	0	$412	$624	$1,024	$1,408

The seed yield losses described above are much higher than those for the 1993-94 season with a highest calculated loss of $740/ha from plots infested with between 52 to 103 PM.

Thousand seed weight was also reduced significantly (P< 0.05) in the 'PM 10' and 'PM80' treatments. The increases in thousand seed weight from 'PM 10' to 'PM 40(6 wks)' may have been the result of more assimilates being available for fewer seed per inflorescence as hypothesised by Schroeder (1995). The reason why this trend has not extended to the 'PM 80'

plots (with even higher thousand seed weights) may be due to whole inflorescence mortality from intensive feeding pressure (Plate 12 and 13) resulting in harvested seed from late inflorescence production following the removal of the PMs. Seeds from the late inflorescences are likely to be poorly provisioned as the provisioning priority of the plant switches from reproductive back to vegetative growth (refer to Chapter 1).

As expected, total seed yield decreases occurred with decreasing total number of inflorescences. When the different PM densities were plotted against these two variables a strong correlation was shown (Figure 34). This, in effect, summarises the effect of PM densities on resultant seed yield and can be used to develop action thresholds for the control of PM with insecticides and other tactics.

PM 40 time impact

The impact of 40 PM on inflorescence components over the three time periods indicated that the plants rapidly recovered and almost compensated for inflorescence loss early on in the 'PM 40(2 and 4 wks)' treatments (Figure 31a). At peak flowering (2 January), inflorescences in these two plots were higher than the control plot, but lower in the 'PM 40(6 wks)' treatment where PM were still caged. However, Figure 31b indicates that the injury symptoms caused by 'PM 40(2 and 4 wks)' can remain for one to two weeks following PM removal. The loss in inflorescences did not significantly ($P > 0.05$) affect total seed yields from the three 'PM 40(6 wks)' treatments (Table 25).

There was high mortality of PM in the three 'PM 40 Time Impact' treatments ranging from 64 ('PM 40(2 wks)')to 38 ('PM 40(4 wks)') and 31% ('PM 40(6 wks)') successively at two weekly intervals (Table 26). It would appear from these results that PM do not survive well when caged. The cage size may play a role in this and adult PM were observed crawling over the cage material trying, possibly, to be looking for a way out of the cage. The longevity of adult PM is not known. There may have been a lack of mating partners and oviposition sites within the cage or a decrease in suitable food causing them to search for better sites.

The survival of PM in cages was higher when there were fewer PM present (Table 26). The decrease in PM survivors with increased infestation numbers correlated closely to seed yields (Figure 33). This indicates that survivorship of PM may be a function of density dependent

factors, where at low infestations the food source is adequate to carry a higher proportion of PM through to maturity (e.g., PM 10) while competition for a limited food resources means lower PM survival (e.g., PM 80). At higher densities cannibalism may increase to levels similar to those found by Khattat and Stewart (1977). The numbers surviving in the 'PM 40(6 wks)' and '80' treatments (Table 26) indicate that 12 PM may be the carrying capacity of the white clover plants grown within the cage environment.

BGLA impact

The highest impact on inflorescence components and seed yields were from the 'Full' and 'Early-late infestation' treatments (Tables 27 and 28) where inflorescence injury (Figures 35b) occurred later in the season around peak flowering. Injury was not apparent until soon after BGLA was removed from the 'Full' and 'Early-late infestation' treatments (Figure 35b) indicating a delayed effect of feeding. The increase in numbers in these two treatments was also considerably higher than the other treatments (Table 29), indicating that plant growth stage may influence the rate reproduction. The large numbers of aphids caused dehydration of the plants to the extent that in the 'Early-late infestation' plots, spraying was required earlier than anticipated to save the plants. Water stress was not a limiting factor in any of the other plots. The feeding by aphids had an effect on first quality thousand seed weight (Table 28) similar to the moisture stress effects found by Clifford (1987). Of note with the thousand seed weight data was the time of aphid removal as it affected ovule provisioning through to mature seed. Maximum ovule numbers are retained at a base provisioning level (thousand seed weight). Hence food reserves in the 'Full' and 'Early-late infestation' treatments suffered considerably from intense BGLA feeding pressure as evidenced in the high increase in numbers. While water stress reduces plant vigour and resultant thousand seed weight in the field, large numbers of BGLA may accentuate this loss. Therefore, BGLA needs to be eliminated in dry-land cropping systems when it reaches a prescribed threshold or after infestation flights, or, if irrigation is available, water is applied to compensate for moisture losses.

There was evidence of inflorescence injury caused by BGLA (Table 27, Figures 35a,b), which could either be caused by mechanical feeding or as a result of assimilate loss. Although injury was evident, seed yield was not significantly affected in the 'Full' or 'Early-late' treatment (Table 28).

The previous chapters have focused on identifying the impact and control of PM and BGLA in white clover crops. During the field studies, data were also collected on the natural arthropod enemies commonly found in white clover crops. The next chapter examines the temporal and

spatial distribution of both pest species with their natural predators to determine whether any synchrony between populations exists and, therefore, potential control that these natural enemies may exert.

CHAPTER SIX

SYNCHRONY BETWEEN PREDATORY ARTHROPODS AND INSECT PESTS IN WHITE CLOVER SEED CROPS

INTRODUCTION

Bluegreen lucerne aphid (BGLA, *Acyrthosiphon kondoi* Shinji) was the most abundant insect pest in white clover crops encountered during the 1993-94 (Schroeder 1995), and 1994 to 1996 (current study) sampling periods. Leathwick and Winterbourn (1984) studied predation on BGLA and pea aphid (*Acyrthosiphon pisum* (Harris)) in a Lincoln lucerne crop and showed that over 70% of the gut contents from the four most abundant predators found (Pacific damsel bug, *Nabis kinbergii* (Reuter); elevenspotted ladybird, *Coccinella undecimpunctata* L.; Tasmanian lacewing, *Micromus tasmaniae* (Walker); and European harvestman, *Phalangium opilio* L.) gave positive precipitin reactions to aphid-induced rabbit antiserum. European harvestman was considered a major aphid predator in lucerne crops because of the high numbers (5.1 ± 0.5/20 sweeps) found during night collections.

Because of a lack of synchrony of their life histories with those of their prey, the effectiveness of some predators in reducing aphid populations may be limited (Cameron *et al.*, 1980). Nevertheless, ladybirds have been occasionally noted providing complete control of lucerne aphids (Cameron *et al.*, 1980). In a field survey by Schroeder (1995), a decrease in BGLA numbers in white clover crops corresponded with rapid increases of ladybird adults and larvae, damsel bug adults and nymphs, and larval lacewing numbers. Ladybird and lacewing numbers then decreased in close synchrony with the decline of BGLA populations. This suggests that the decline in BGLA populations may be due to predation by these species.

With respect to other predators, European harvestman was not found in any numbers until full crop bloom (mid to late December), while hover fly larvae (*Melangyna novaezelandiae* (Macquart) and *Melanostoma fasciatum* (Macquart) peaked near the end of bloom (mid to late January). These species are, therefore, poorly synchronised with the early BGLA population increase. However, they may reduce BGLA populations later in the growing season (Schroeder 1995). Money spiders

(predominantly *Lepthyphantes tenuis* (Blackwell)) are likely to feed on fallen aphids landing in their webs (Sunderland *et al.* 1986), but an increase in money spiders did not correspond to an increase in BGLA numbers (Schroeder 1995). Some wolf spiders, e.g., *Lycosa* sp., were collected in low numbers throughout the season, however, they are poor climbers and may have an impact only on fallen aphids (Leathwick & Winterbourn 1984).

Although potato mirid (PM, *Calocoris norvegicus* (Gmelin) was most abundant at the edges of wheat fields in England (Moreby 1991a), carabid beetles in the conservation headlands appeared to have little effect in reducing this species. The prey composition of carabid species associated with New Zealand white clover crops has not been studied. However, it appears that they are poor climbers (S.D.Wratten pers. comm.) and occur at lower densities compared with those species in English agricultural systems. It is likely that carabids associated with white clover crops are likewise ineffective control agents for PM (due to PM's high mobility and the abundance of other prey like BGLA (Schroeder 1995)).

The objective of the research presented in this chapter was to investigate more closely the spatial and temporal distribution of natural enemies found in white clover crops and their relationship to prey densities.

MATERIAL AND METHODS

Each of the field experiments conducted during this research programme gathered data on the common arthropod predators collected in samples. The most extensive data were those collected from the 24 crops monitored during the 1994-95 season. Travel distances between growing areas and the time taken to sample each crop (approximately one hour) made it impossible to sample all 24 crops on the same day. Therefore, all crops in the Darfield, Sheffield, Lincoln and Southbridge areas were sampled during one week, followed by crops from the other areas during the next week. The data collected from each pair of weeks were analysed as one sampling date and are presented as such in the following results. These data were analysed to determine overall trends in the spatial and temporal distribution of the common arthropod predators and the two main insect pests (BGLA and PM nymphs). The field sampling methods are described in the respective 'Material and Methods' sections of chapters 2 and 4.

Data collected from the 24 Canterbury white clover crops during the 1994-95 season were analysed by analysis of variance using the Poisson error distribution to determine whether any differences in the spatial and temporal distributions occurred for each natural enemy species. Correlation analysis was then used to determine the synchrony of each natural enemy species with PM nymphs and BGLA. Standard correlation coefficients were used to identify significant ($P< 0.05$) correlations between pest and natural enemy densities at a particular sampling position at one time with the densities from the same position at a later time. In this way, the spatial distribution of pest and natural enemy could be compared on a temporal scale, any lag period resulting from a rapid pest population increase could be linked with a natural enemy population increase. Significant ($P< 0.05$) correlation coefficients are presented in table form and overall trends (all sample positions pooled) between natural enemy species and BGLA densities are shown graphically. Analysis of variance was also carried out to determine the effects of different insecticides (Chapter 4) on natural enemy densities. All analyses were carried out using the Genstat® for Windows statistical package (© Lawes Agricultural Trust, IACR, Rothamsted, U.K.). The effect of different insecticides on predator numbers was also evaluated using the data collected from Chapter 4.

RESULTS

The following natural enemies were collected during the 1994-95 season (Table 32). Of these species, carabid beetles, Pacific damsel bugs, and wolf spiders were found in low numbers (< $1/m^2$) and will not be considered further.

Table 32. Arthropod predators collected from 24 Canterbury white clover fields during the 1994-95 crop monitoring season.

Common Name	Scientific Name	Stage(s) counted	
		Adult	Immature
Elevenspotted ladybird	*Coccinella undecimpunctata* L.	✓	✓
Tasmanian lacewing	*Micromus tasmaniae* (Walker)	✓	✓
Pacific damsel bug*	*Nabis kinbergii* (Reuter)	✓	✓
Large hover fly and	*Melangyna novaezelandiae* (Macquart)		✓
Small hover fly	*Melanostoma fasciatum* (Macquart)		✓
Carabid beetles*	several species	✓	
Money spiders	*Lepthyphantes tenuis* (Blackwell)	all stages grouped	
European harvestman	*Phalangium opilio* L.	all stages grouped	
Wolf spiders*	*Lycosa hilaris* Koch	all stages grouped	

* refers to species collected at $<1/m^2$.

Plate 16. Elevenspotted ladybird larvae (top right), prepupa (middle bottom) and pupa (darkest) on marker peg.

Plate 15. Elevenspotted ladybird adult (4-5 mm) feeding on aphid.

Plate 17. Tasmanian lacewing larva (5 mm) consuming an aphid.

Plate 18. Tasmanian lacewing adult (7-10 mm) chewing on an aphid.

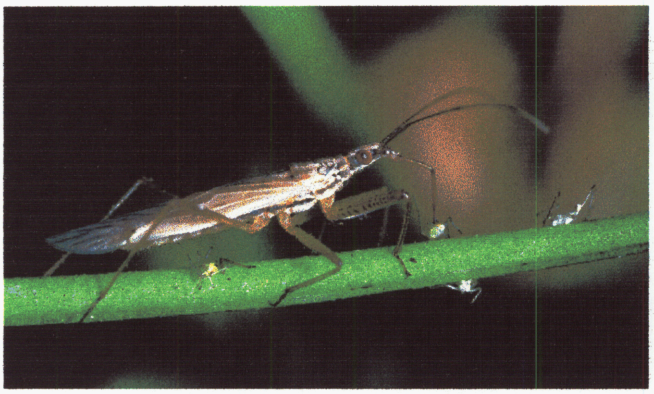


Plate 19. Pacific damsel bug adult (7-8 mm) feeding on an aphid.

Plate 20. Hover fly larvae (7 mm).

Plate 21. European harvestman (50 mm).

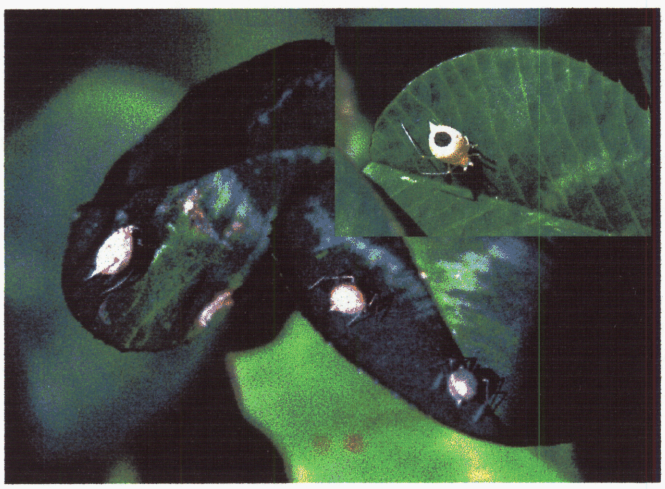


Plate 22. Parasitised bluegreen lucerne aphids, commonly referred to as mummies. Inset shows parasitoid exit hole from mummy.

Plate 23. Bluegreen lucerne aphid infected by *Entomophthora* fungus. This fungus can rapidly reduce aphid numbers under cool humid conditions.

Ladybirds

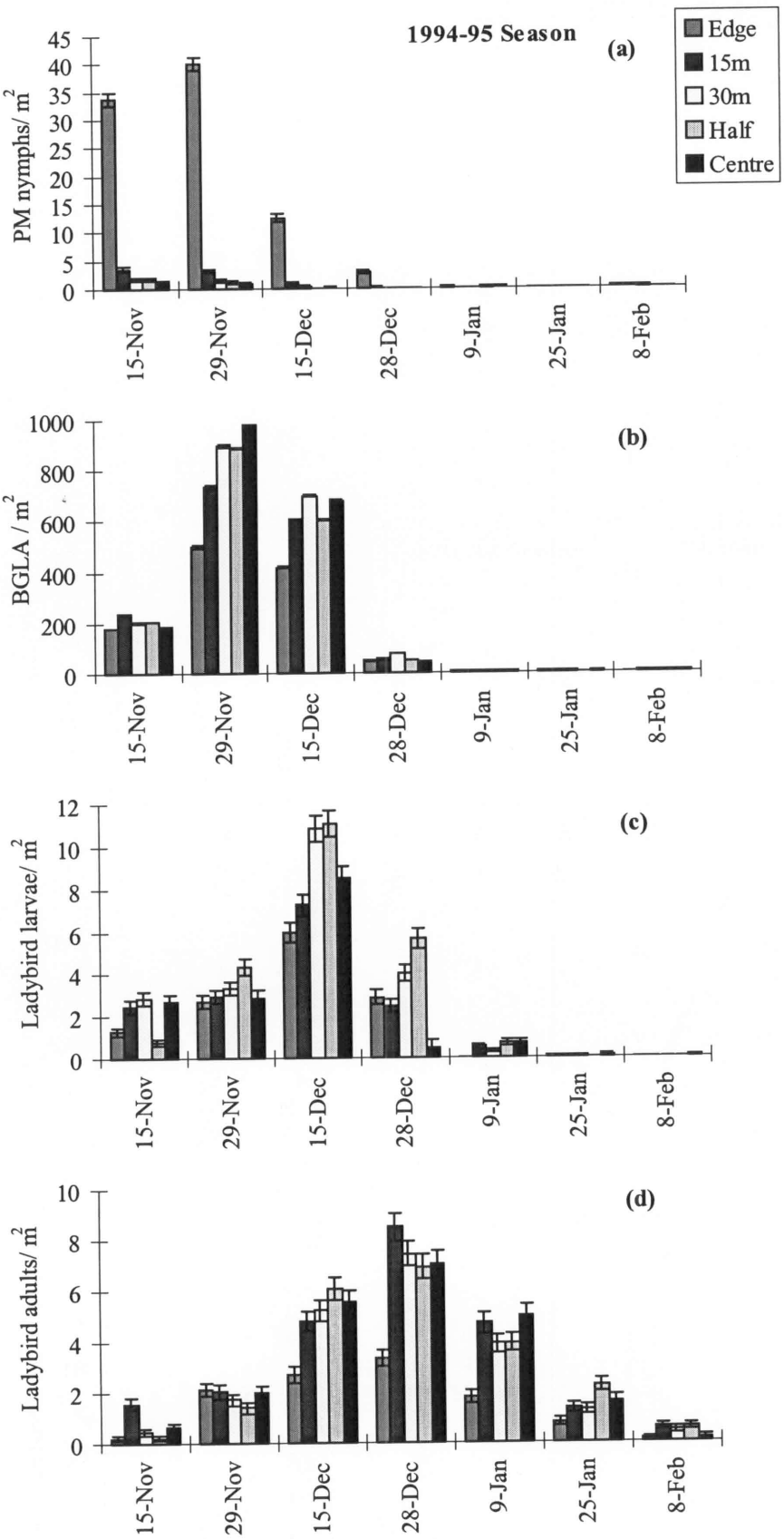


Figure 37. The density (± SE) of ladybird larvae (c) and adults (d) compared with PM nymphs (a) and BGLA (b) during the 1994-95 season in 24 Canterbury white clover crops.

The densities of ladybird larvae and adults (Plates 15 and 16) were significantly ($P< 0.001$) different over time (Figures 37c and d) and between the different growing regions. Larval densities peaked during mid December and ranged from 3 ± 0.5/m^2 (Lincoln) to 22 ± 1.4/m^2 (Darfield). Peak densities of ladybird adults occurred during late December and ranged from 3 ± 0.5/m^2 (Methven) to 16 ± 1/m^2 (Darfield). Overall, there were significant ($P< 0.01$ and 0.001) differences in the densities of ladybird larvae and adults at the different sampling positions (Figure 37d) with fewer being present at the crop margins than further into the crop.

There were no significant ($P> 0.05$) correlations or trends found between the densities of PM nymphs and either ladybird larvae or adults when data were pooled for each sampling position at each sampling period. However, ladybird larval densities were correlated with BGLA densities over time (Table 33 and Figure 38). Trends in ladybird larval and BGLA densities were similar during the first and last two sampling periods, however, there was a lag of approximately two weeks at peak densities (Figure 38).

	Ladybird larvae						
BGLA	15 Nov	29 Nov	15 Dec	28 Dec	9 Jan	25 Jan	8 Feb
15 Nov	**	*					
29 Nov			***				
15 Dec			**	***			
28 Dec					***		
9 Jan							
25 Jan						***	
8 Feb							***

Table 33. Correlation table showing the significant (* $P< 0.05$, ** $P< 0.01$ and *** $P< 0.001$) interactions between BGLA and ladybird larval densities pooled for each sampling position in 24 Canterbury white clover crops during the 1994-95 season.

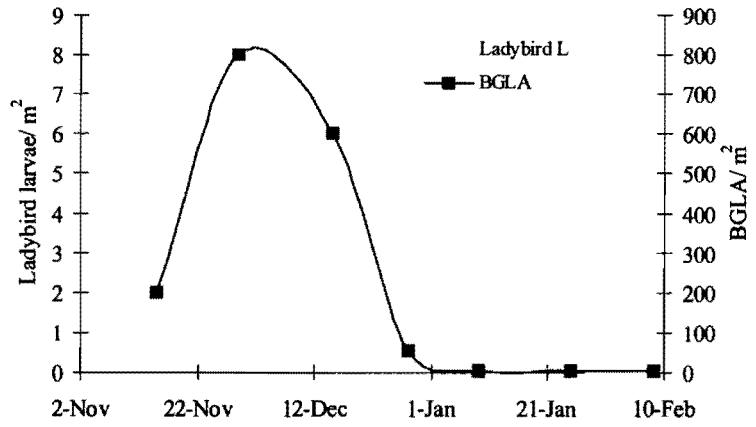


Figure 38. Mean densities (all data pooled) of BGLA and ladybird larvae in 24 Canterbury white clover crops during the 1994-95 season.

The overall trend in correlations between BGLA and adult ladybird densities was not as strong as that for ladybird larvae (Table 34 and Figure 39). There was an approximate four week lag between BGLA and ladybird adult peak densities.

BGLA	Ladybird adults 15 Nov	29 Nov	15 Dec	28 Dec	9 Jan	25 Jan	8 Feb
15 Nov	*	*					
29 Nov			*	***			
15 Dec				**			
28 Dec							***
9 Jan			**				
25 Jan							
8 Feb							***

Table 34. Correlation table showing the significant (* P< 0.05, ** P< 0.01 and *** P< 0.001) interactions between BGLA and ladybird adult densities pooled for each sampling position in 24 Canterbury white clover crops during the 1994-95 season.

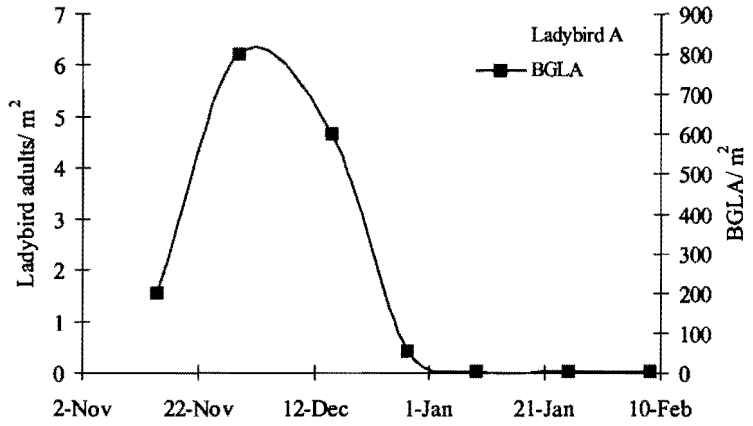


Figure 39. Mean densities (all data pooled) of BGLA and ladybird adults in 24 Canterbury white clover crops during the 1994-95 season.

Lacewings

There were significant (P< 0.001) differences between the densities of lacewing larvae (Plate 17, Figure 40c) and adults (Plate 18, Figure 40d) over time and between the different growing regions during the 1994-95 season. Lacewing larval densities peaked in mid December and densities during this peak period ranged from 1.0 ± 0.3/m^2 in Southbridge to 9.4 ± 0.9/m^2 in Darfield. Adult densities peaked two weeks later than larvae in late December. During this period, densities ranged from 5.4 ± 0.7/m^2 (Lincoln) to 28 ± 2/m^2 (Timaru). Overall, there were no significant (P> 0.05) differences between sampling positions at each sampling period for lacewing larvae or adults (Figures 40c and d).

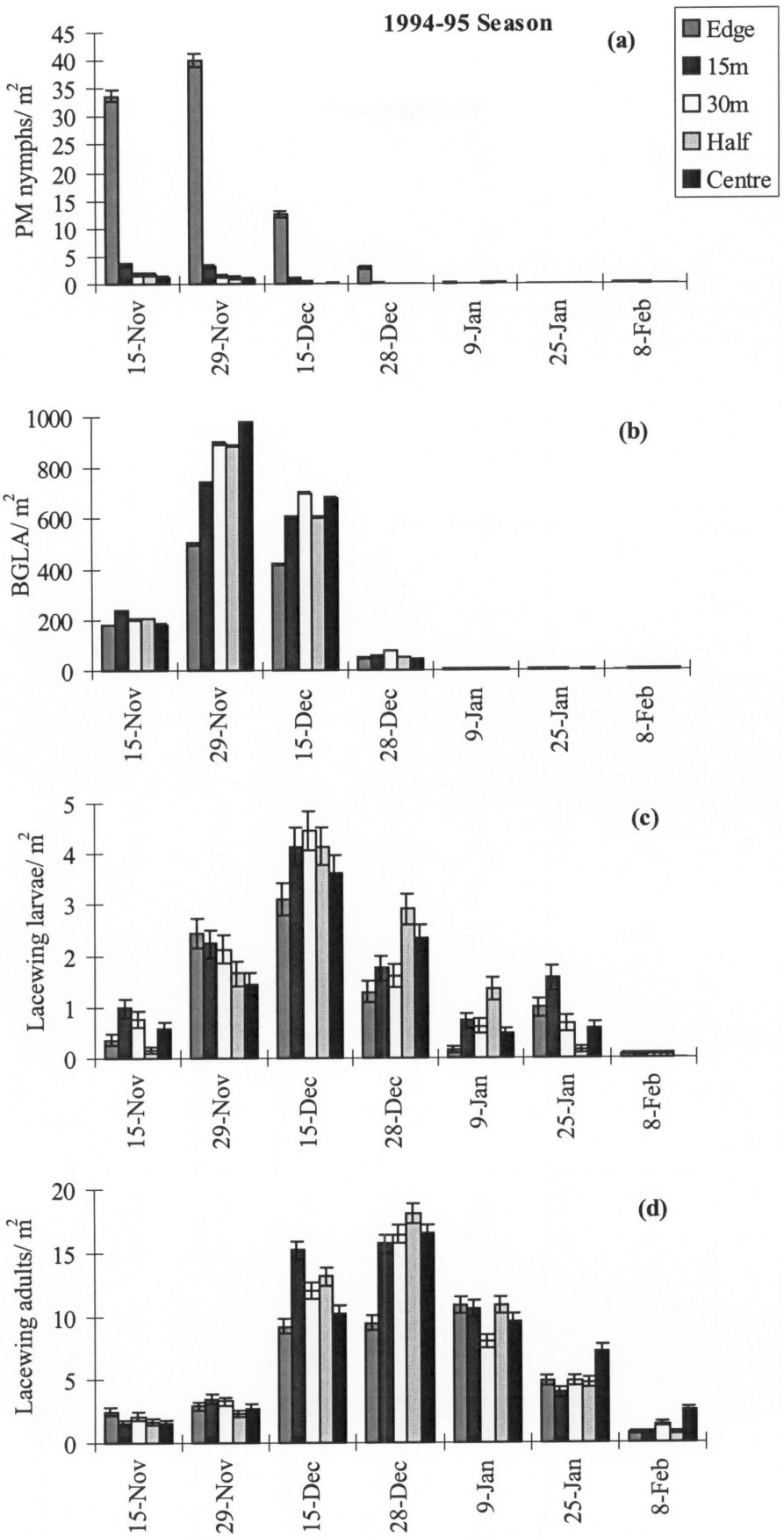


Figure 40. The density (± SE) of lacewing larvae (c) and adults (d) compared with PM nymphs (a) and BGLA (b) during the 1994-95 season in 24 Canterbury white clover crops.

BGLA	Lacewing larvae 15 Nov	29 Nov	15 Dec	28 Dec	9 Jan	25 Jan	8 Feb
15 Nov	***						
29 Nov		**					
15 Dec			***				
28 Dec							
9 Jan							
25 Jan						***	
8 Feb							

Table 35. Correlation table showing the significant (** P< 0.01 and *** P< 0.001) interactions between BGLA and lacewing larval densities pooled for each sampling position in 24 Canterbury white clover crops during the 1994-95 season.

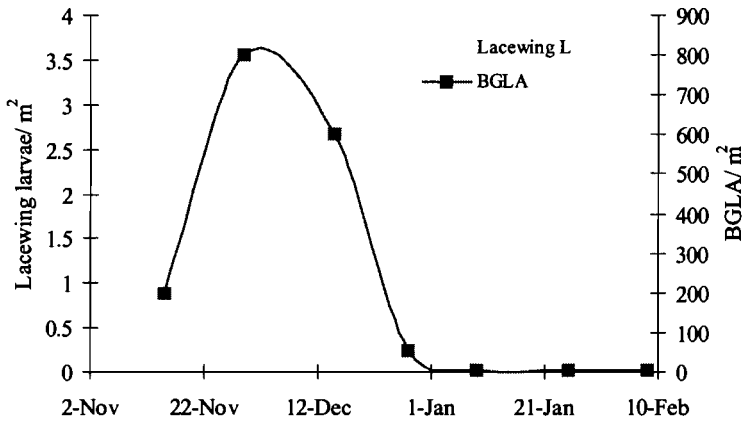


Figure 41. Mean densities (all data pooled) of BGLA and lacewing larvae in 24 Canterbury white clover crops during the 1994-95 season.

While there were some significant (P< 0.05) correlations between PM nymphal densities and lacewing larvae and adult densities when data were pooled for each sampling position at each sampling period, these were sporadic and showed no overall trend. There were, however, significant (P< 0.01 and 0.001) correlations between BGLA and lacewing larval densities that showed that both species had a similar temporal trend (Table 35) with no lag between the respective densities. However, graphically there is a clear (approximately two week) lag between the BGLA peak and lacewing peak larval densities (Figure 41).

BGLA	Lacewing adults 15 Nov	29 Nov	15 Dec	28 Dec	9 Jan	25 Jan	8 Feb
15 Nov	*						
29 Nov				***			
15 Dec							
28 Dec						**	***
9 Jan							
25 Jan				*	*	**	
8 Feb						***	***

Table 36. Correlation table showing the significant (* P< 0.05, ** P< 0.01 and *** P< 0.001) interactions between BGLA and lacewing adult densities pooled for each sampling position in 24 Canterbury white clover crops during the 1994-95 season.

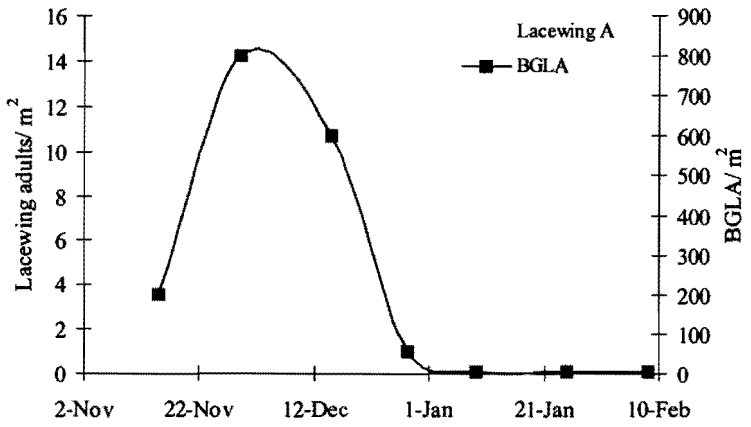


Figure 42. Mean densities (all data pooled) of BGLA and lacewing adults in 24 Canterbury white clover crops during the 1994-95 season.

There were no clear relationships between BGLA and lacewing adult densities (Table 36). However, there was a significant (P< 0.001) correlation between BGLA and lacewing adult densities at their respective peak densities and again (as for ladybird adults) a lag (Figure 42) is apparent.

Other Common Natural Enemies

Overall, the densities of money spiders were significantly (P< 0.001) different between growing regions. In early January, densities ranged from 12 ± 1/m^2 (Ashburton/Barrhill) to 49 ± 2/m^2 (Sheffield). There was a significant (P< 0.001) difference in money spider densities over time, but no significant (P> 0.05) differences were found between different sampling positions (Figure 43c).

No significant (P> 0.05) correlations were found between PM nymph and money spider densities when data were pooled for each sampling position at each sampling period. There were some significant (P< 0.05 and 0.001) correlations found between BGLA and spider money densities when the data were pooled at each sampling position at each sampling period. However, there were no correlation trends between the two species over time (Table 37 and Figure 44). There was a six week lag between BGLA and money spiders reaching their respective peak densities.

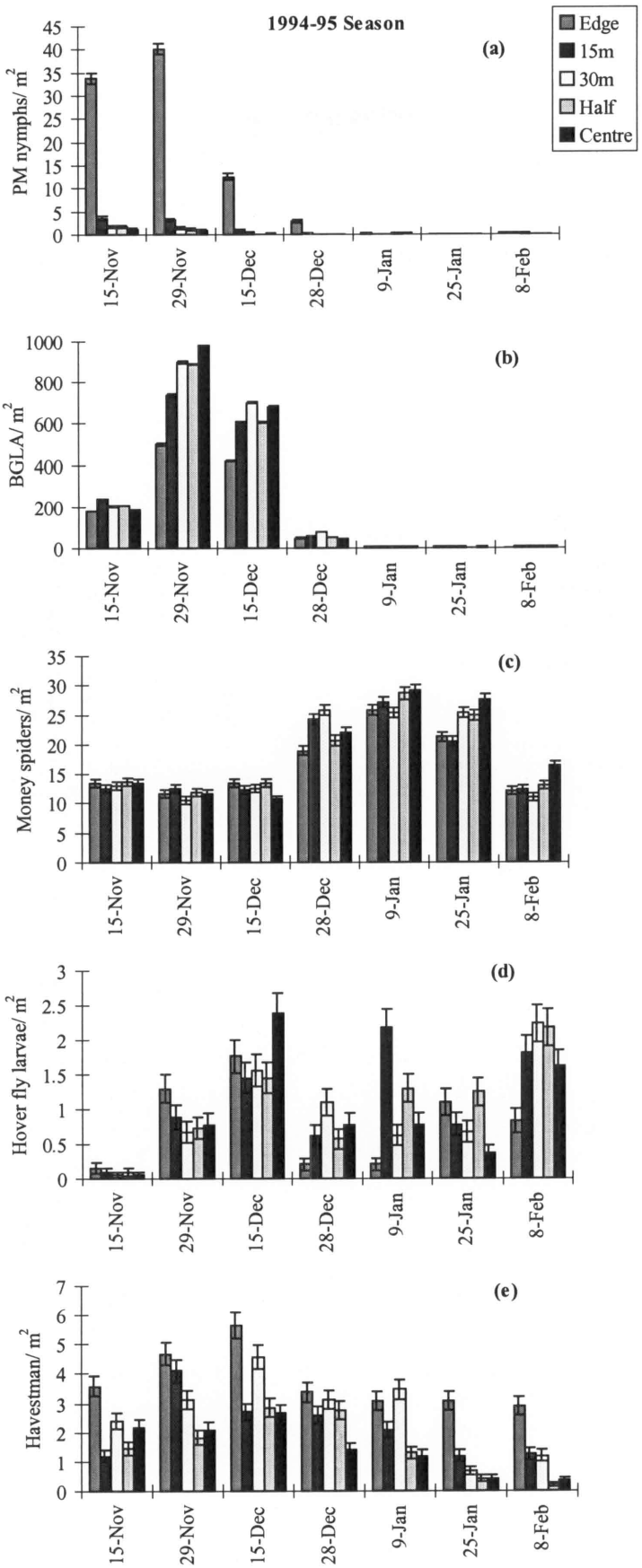


Figure 43. The density (± SE) of (c) money spiders, (d) hover fly larvae, and (e) European harvestman numbers compared with (a) PM nymphs and (b) BGLA during the 1994-95 season in 24 Canterbury white clover crops.

BGLA	Money spiders 15 Nov	29 Nov	15 Dec	28 Dec	9 Jan	25 Jan	8 Feb
15 Nov							
29 Nov							
15 Dec							
28 Dec					***		***
9 Jan					*		
25 Jan						***	
8 Feb					***		***

Table 37. Correlation table showing the significant (* P< 0.05 and *** P< 0.001) interactions between BGLA and money spiders densities pooled for each sampling position in 24 Canterbury white clover crops during the 1994-95 season.

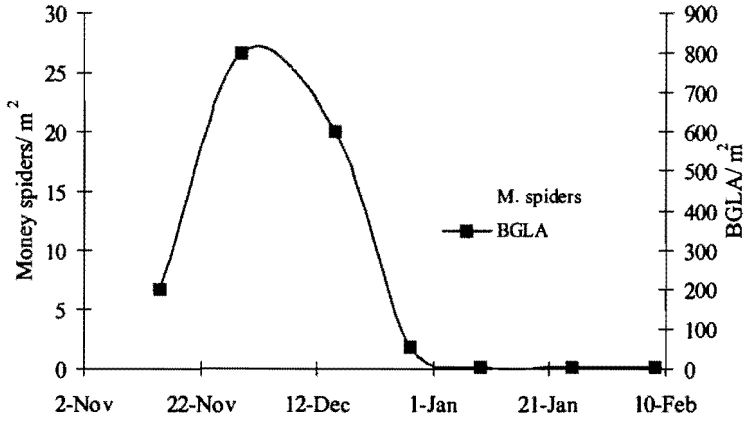


Figure 44. .Mean densities (all data pooled) of BGLA and money spiders collected in 24 Canterbury white clover crops during the 1994-95 season.

Overall, the density of hover fly larvae (Plate 20) during the 1994-95 season was significantly (P< 0.001) different over time and between the growing regions. No significant (P> 0.05) differences were found in the densities at different sampling positions. Hover fly larval densities peaked in early February (Figure 43d) and ranged from 13.8 ± 1.1/m^2 in Southbridge to 0/m^2 in all the other growing regions.

While there were some significant (P< 0.05) correlations between PM nymphal numbers and hover fly larval numbers when data were pooled for each sampling position at each sampling period, these did not follow any trend. There was, however, a relationship between BGLA and hover fly larval densities up until 9 January described by significant (P< 0.05 and 0.001) correlations (Table 38 and Figure 45). There was a two week lag between BGLA and hover fly larval densities. A second peak in hover fly larvae densities occurred later during January and February (Figure 45) but was unrelated to BGLA densities.

BGLA	Hover fly larvae 15 Nov	29 Nov	15 Dec	28 Dec	9 Jan	25 Jan	8 Feb
15 Nov							
29 Nov		***	*	*			
15 Dec			***	***			
28 Dec					*		
9 Jan							
25 Jan							
8 Feb							

Table 38. Correlation table showing the significant (* P< 0.05 and *** P< 0.001) interactions between BGLA and hover fly larval densities pooled for each sampling position in 24 Canterbury white clover crops during the 1994-95 season.

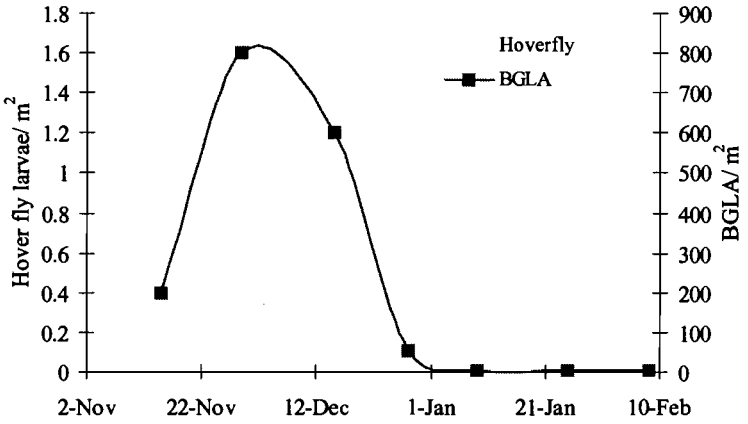


Figure 45. Mean densities (all data pooled) of BGLA and hover fly larvae in 24 Canterbury white clover crops during the 1994-95 season.

Overall, European harvestman (Plate 20) densities were significantly (P< 0.001) different over time and between the growing regions during the 1994-95 season. There was a significant (P< 0.001) difference in European harvestman densities at different sampling positions, with higher densities at the 'edge' (Figure 43e). The mean highest densities (5.6/m^2 ± 0.5) occurred in the edge occurred in mid-December and ranged from 0.5 ± 0.2 in Timaru to 13 ± 1/m^2 in Lincoln.

Of all the natural enemy species studied, only European harvestman densities showed some synchrony with PM nymphal densities when data were pooled for each sampling position at each sampling period (Table 39 and Figure 46). Significant (P< 0.05 to 0.001) correlations were found between PM nymphs and European harvestman that indicated a trend between species densities later in the season when both densities were declining. There was a two week lag period between PM nymphal and European harvestman peak densities (Figure 46).

PM nymphs	European harvestman: 15 Nov	29 Nov	15 Dec	28 Dec	9 Jan	25 Jan	8 Feb
15 Nov							
29 Nov							
15 Dec					**		
28 Dec	**				***	**	**
9 Jan						**	*
25 Jan							
8 Feb				***	***		*

Table 39. Correlation table showing the significant (* P< 0.05, ** P< 0.01 and *** P< 0.001) interactions between PM nymphal and European harvestman densities pooled for each sampling position in 24 Canterbury white clover crops during the 1994-95 season.

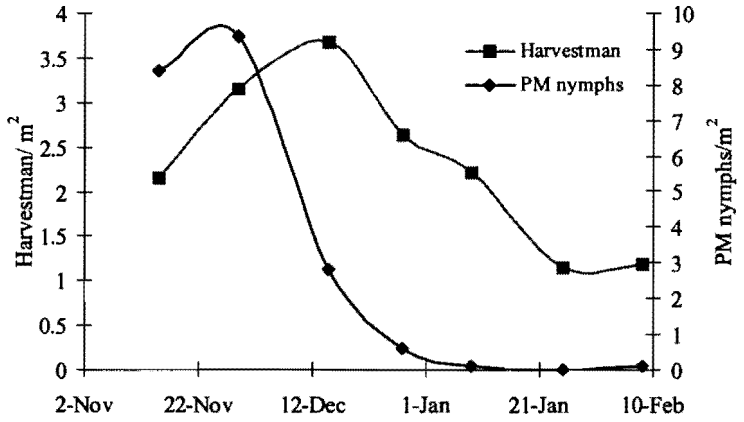


Figure 46. Mean densities (all data pooled) of PM nymphs and European harvestman in 24 Canterbury white clover crops during the 1994-95 season.

BGLA	European harvestman: 15 Nov	29 Nov	15 Dec	28 Dec	9 Jan	25 Jan	8 Feb
15 Nov							
29 Nov							
15 Dec							
28 Dec					***		
9 Jan							
25 Jan							
8 Feb					***		

Table 40. Correlation table showing the significant (*** P< 0.001) interactions between BGLA and European harvestman densities pooled for each sampling position in 24 Canterbury white clover crops during the 1994-95 season.

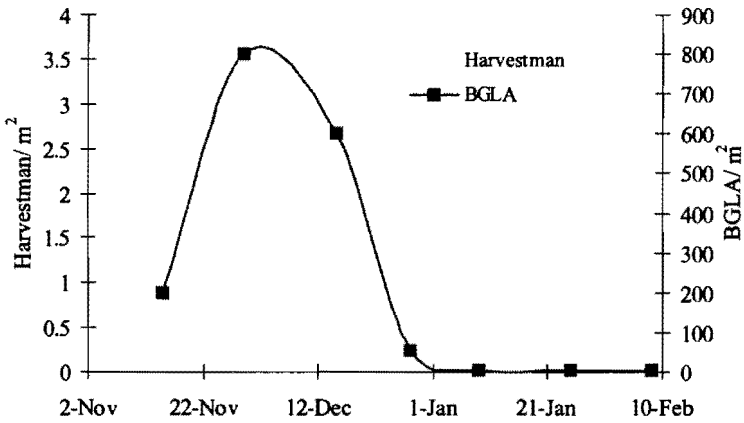


Figure 47. Mean densities (all data pooled) of BGLA and European harvestman in 24 Canterbury white clover crops during the 1994-95 season.

Two significant (P< 0.001) correlations were found between BGLA and European harvestman densities (Table 40). The overall trend in density between the species when data were pooled for each sampling position at each sampling period is visible, but weaker than the others shown

previously. There was a lag of two weeks between the peak densities of BGLA and European harvestman (Figure 47).

The Effects of Insecticides on Natural Enemy Numbers

Several insecticides were tested for their efficacy against insect pests and their impact on natural predator numbers (Chapter 4). The following results were obtained from the natural enemy data.

Of the three insecticides applied in the field experiment there were significant ($P< 0.05$) reductions of ladybird larvae at 2 and 4 DAT, lacewing larvae at 2 DAT, and lacewing adults at 4 DAT in the lambda-cyhalothrin plots when compared with numbers in the control plots. Ladybird adult numbers were significantly ($P< 0.05$) lower in the pirimicarb treatment at 2 DAT compared to the control plots. The only other significant difference in natural enemy numbers occurred at 2 DAT when money spider numbers were significantly ($P< 0.05$) higher in the insecticide-treated plots compared with the control plots. None of the treatments significantly ($P> 0.05$) affected hover fly larval or European harvestman numbers.

DISCUSSION

As with this study, populations of five arthropod predator species found in the Canterbury growing region have been shown to be temporally synchronised with BGLA in white clover (Wightman and Whitford 1982; Schroeder 1995; Schroeder and Clifford 1996) and lucerne crops (Cameron *et al.* 1980; Leathwick and Winterbourn 1984; Rohitha *et al.* 1985). While all predators may prey upon PM, especially during the early instars, no clear synchrony of specific predators with PM nymphs was shown. Schroeder and Clifford (1996) suggested that PM is faster moving than other potential hosts (e.g., BGLA) and may escape capture by predators. Other factors may also be involved in prey preference (e.g., host abundance, host defence mechanisms) that could be evaluated to determine the effectiveness of specific natural enemies on selected hosts.

BGLA was the predominant insect pest found in Canterbury white clover crops during both seasons. This species probably also represented the highest pest biomass and readily available food source for predators. The average weight of one BGLA estimated from Rohitha's study (1979) was 1 mg. The mean highest density of BGLA collected during the 1994-95 season was $800/m^2$ in late November, which relates to 800 mg/m^2. In comparison, PM nymphs reached a

maximum 40/m^2 in the 'edge' position, which at an estimated 4 mg each, corresponds to 160 mg/m^2. As such, BGLA probably represents the highest host biomass by species available for predation. Cameron *et al.* (1980) suggested the effectiveness of predators in reducing BGLA populations may be limited, due to the lack of synchrony of their life histories with their prey. Nevertheless, the predominant predator collected in this study, elevenspotted ladybird, has occasionally been noted to provide 'complete control' of BGLA in lucerne crops (Cameron *et al.* 1980).

Ladybirds

Elevenspotted ladybird (Plates 15 and 16) was introduced to New Zealand from Europe in 1874, as one of the first attempts at biological control of aphids (Hagen 1962). It is now the most commonly encountered ladybird species in field crops and can occasionally eliminate aphids in lucerne (Cameron *et al.* 1980). However, this was not the case in this and other studies in this thesis. Generally though, this species is not common in spring aphid populations and provides unpredictable control in summer and autumn (Thomas 1989). Despite the occurrence of large numbers at times, elevenspotted ladybird was not considered an efficient predator for aphid control in lucerne, as its development rate was too slow to keep up with rapidly increasing aphid populations especially during spring (Thomas 1989). Ladybird numbers may also be reduced by larval cannibalism of unhatched eggs and smaller weaker larvae (given a lack of prey), and by parasitism. A braconid wasp, *Dinocampus coccinellae* (Schrank), regularly parasitises up to 90% of the adult ladybirds (Thomas 1989). The combination of larval cannibalism and parasitism may account for the lack of effectiveness of ladybirds reported by Thomas (1989).

The effect of ladybird predation on BGLA in white clover crops has not been studied. However, in this study BGLA numbers increased at a faster rate than those of ladybirds and other natural enemies and were similar to BGLA rates in lucerne reported by Rohitha (1979). Generally, high numbers of ladybirds corresponded to high numbers of BGLA. However, a two week and four week lag was shown between BGLA populations and ladybird larvae and adults, respectively. While the lag in the populations could be explained by typical predator-prey dynamics, the time taken for ladybird larvae to develop into adults could be the main contributing factor to the later adult peak. Rohitha and Penman (1983) found that BGLA had a lower development threshold of 2.63^{0}C, but had maximum reproductive capacity at 11^{0}C. The temperature-development rates of ladybirds requires studying to determine whether synchrony between BGLA and ladybirds is limited by different temperature thresholds.

In the laboratory, Leathwick and Winterbourn (1984) found that elevenspotted ladybird adults consumed 28 (70%) out of 40 third and fourth instar pea aphids in a 48 hour period. Relating this information to the densities of ladybirds and BGLA in this study (assuming that no other mortality factors were involved), may provide information on the ability of elevenspotted ladybirds to reduce BGLA populations. However, such extrapolations were shown to be highly inaccurate in a study by Frazer and Gilbert (1976) who investigated the impact of another ladybird species (*Coccinella trifasciata* L.) on pea aphid predation. One of the main problems associated with the extrapolation was the uncontrolled variables in the field compared with the laboratory (e.g., increased range of alternative host species and weather factors). The other main problem was the significant underestimation of ladybird numbers by the visual sampling method used. Frazer and Gilbert (1976) found that *C. trifasciata* was active during the day and higher numbers were observed under hotter temperatures. This was also the case with *C. undecimpunctata* in lucerne (Leathwick and Winterbourn 1984).

Therefore, to achieve a reliable estimate of the ladybird densities two main factors need to be considered. First, time of sampling should ideally coincide with peaks in natural predator activity. If ladybirds are more active and readily collected during the heat of the day then sampling during this time would give a more accurate estimate. An example of a modified sampling programme was conducted by Leathwick and Winterbourn (1984) who also conducted night sampling in a lucerne crop and found significantly higher numbers of European harvestman and Pacific damsel bug. Second, sampling efficiency needs to be evaluated. If a sampling method is consistently underestimating the population mean, a correction factor could be used to adjust sample numbers. The sampler used in this study has not been evaluated for its extraction efficiency of arthropods in white clover seed crops. MacLeod *et al.* (1994) found that the prototype suction sampler captured significantly higher numbers of polyphagous predators in cereals and grassy habitats and aphids in cereals compared with a traditional D-Vac suction sampler. Testing to determine the efficiency of the suction sampler used in this study in a variety of white clover crops (e.g., plant densities) and under a range of different conditions (e.g., temperature) is recommended.

Lacewings

Tasmanian lacewing feeds on a range of aphid species with a preference for wingless compared with winged forms, but it will also attack mealy bugs (Leathwick 1989). Tasmanian lacewing larvae move rapidly in search of prey and use their mandibles to hold aphids in the air while sucking out their body fluids (Plate 17). The adult uses its mandibles for biting and chewing and

will devour the entire aphid body (Plate 18). Its distribution was relatively uniform throughout the crops sampled and, therefore, corresponded spatially with BGLA. The correlation data from this study indicated that Tasmanian lacewing larval densities also had good temporal synchrony with BGLA densities. Leathwick (1989) found that large populations of lacewing adults in lucerne fields were accounted for by recruitment rather than immigration. Evidence that immigration was not involved in the occurrence of large populations was gathered using directional flight traps around a field perimeter. Leathwick (1989) reported that Tasmanian lacewing has a high efficiency at converting aphids into eggs and is, therefore, able to attain maximum reproductive output at low prey densities. Long adult life, high fecundity and the absence of any form of aestivation or diapause, results in a complete overlap of generations and multiple generations per year. Therefore, of all the natural predators commonly found in white clover seed crops, lacewings appear to be best adapted for the control of BGLA populations.

Leathwick and Penman (1984) found that D-vac sampling underestimated the abundance of first and second instar lacewings and that past studies may have underestimated the abundance of this aphid predator. In this study, higher numbers of adult lacewing than larvae were collected. Low numbers of first and second instar lacewing larval numbers were observed during this study, the majority were third instar larvae. Younger larvae may be more active at night or have the ability to find refuges that reduces their chances of being removed by suction sampling. Therefore, it is expected that lacewing larval numbers were underestimated during this study meaning that their effect on controlling BGLA could have also been underestimated.

Cameron *et al.* (1983) reported that lacewings appeared to be better synchronised with *Acyrthosiphon* spp. populations in lucerne crops. Syrett and Penman (1980) suggested this was due to its low development temperature threshold. Leathwick (1989) found that the temperature threshold for development was 4-5^{0}C and that lacewings had a rapid development and a short preoviposition period, which resulted in a short generation time (49 days at 15^{0}C). This could account for, in part, the close temporal synchrony of lacewing larvae to BGLA densities found in this study.

In prey size choice tests conducted by Leathwick (1989), lacewing adults showed a preference for smaller aphids (44% first instar, 24% second instar, 19% third instar, and 13% fourth instar were selected). The same tests conducted with adult ladybirds (*Coccinella undecimpunctata*) showed a preference for larger instars. Therefore, for each gram of aphids consumed, lacewings remove higher numbers of aphids from the population than ladybirds. These results suggest that lacewings

maybe more efficient predators than ladybirds, however, comparative studies with BGLA as the host would be required to test this hypothesis.

Other common arthropod predators

Of the predators sampled in this study, money spiders were the smallest and are likely to prey upon small insects (e.g., aphids, small flies, and possibly early PM instars) that fall into their webs. Sunderland *et al.* (1986) concluded that linyphiid spider predation on cereal aphid (*Sitobion avenae* (F.)) in wheat fields grown in England accounted for the mortality of 31 aphids/m^2/day during flowering. It was also concluded that spiders could make a significant contribution to aphid control if they occurred earlier in the season when aphid movement was high (Sunderland *et al.* 1986). The increase in money spider density in this study occurred too late (Figure 44) to have any effect on early BGLA infestations and consequent population increases. Overall, it has been found that individual spider species appear incapable of tracking insect pest population changes, either through increases in rates of attack or through changes in effective population densities in local areas (Riechert and Lockley 1984). The absence of any correlation relationship between money spiders and BGLA and PM nymphal densities in this study supports this view. Spiders, for the most part, are non-specific predators, and were not considered as ideal candidates as biological control agents (Dent 1991).

In a study by Leathwick (1989), hover fly larvae were the first predators to appear in lucerne crops in spring, but never reached sufficient levels to have an appreciable impact on aphid numbers. In this study, hover fly larvae correlated well with BGLA densities until late December when hover fly larval densities continued to increased while BGLA densities decreased. However, overall hover fly larval densities were very low during this study. Rohitha *et al.* (1985) found that D-vac sampling under-estimated their numbers. The suction sampler used in this study also may not have been able to extract hover fly larvae efficiently from the clover plants, therefore giving under-estimated numbers.

The two species of hover fly commonly found in white clover crops are known to have aphidophagous larvae and recent work has focused on enhancing their numbers in crops by providing nearby nectar and pollen plant sources (Lövei *et al.* 1993). However, their effectiveness as an aphid predator may be adversely affected by heavy parasitism by the ichneumonid wasp *Diplazon laetatorius* (F.) (Thomas 1989).

Leathwick and Winterbourn (1984) found that aphids tended to move down the lucerne plants at night and that ground-dwelling wolf spiders, *Lycosa* spp., and European harvestman were also more active and were sampled in higher numbers during this time. Of all the predators monitored during this study, only European harvestman showed any significant ($P< 0.05$) correlation trend, and this was with PM nymphal densities. This correlation could be attributed to the high densities of both species found at the edge of the crop. Other studies on the impact of European harvestman predation on insect pests have been done in a range of crops and have focused on aphids (on potatoes, [Dixon and McKinlay] 1989, and Brussells sprouts, [Dempster 1967]) and twospotted spider mite, *Tetranychus urticae* Koch. (on strawberries, [Butcher 1986]). While Leathwick and Winterbourn (1984) found no positive precipitin reactions to PM antiserum to European harvestman gut contents in lucerne, this does not rule out the possibility that European harvestman may have some effect on PM populations in white clover crops. Gut content analyses are required to more accurately assess the effect of predation of PM by European harvestman.

Aphid parasitism was observed in most white clover crops during this study. Mummified aphid bodies were found on leaf surfaces (Plate 22), but the level of parasitism was not quantified. Two aphid parasitoids *Aphidius eadyi* Stary, Gonzales & Hall and *A. ervi* Haliday were released during 1977-79 and 1977-81, respectively (Cameron and Walker 1989). *A. ervi* was slower to establish and spread, but has become predominant over *A. eadyi*. BGLA was the preferred host of *A. ervi*. Hyperparasitoids, particularly *Dendrocerus carpenteri* (Curtis) have had an impact on both parasitoids and may reduce their effect against BGLA (Cameron and Walker 1989). There was a 47% rate of hyperparasitism recorded from *Aphidius* mummies by Walker and Cameron (1981). Leathwick (1989) found that mummified aphids seldom exceeded 1.5% of the aphids present in lucerne samples, and then only after the aphid population had crashed. He concluded that it was unlikely that parasites were contributing significantly to aphid mortality.

During both survey seasons (Chapter 2) the numbers of BGLA decreased rapidly after mid December. This rapid collapse in numbers was also observed by Rohitha *et al.* (1985) in a lucerne crop. Nielson and Barnes (1961) suggested that this collapse was largely due to the fungal pathogen *Entomophthora* spp. (Plate 23), which are favoured by cool humid conditions rather than an increase in alate flights, as recorded by Rohitha and Penman (1986b). There were no field identification or distribution observations made for *Entomophthora* spp. during the course of this study.

Correlation analysis in this study was used to identify whether the densities of common natural enemies found in white clover crops synchronised with those of PM nymph and BGLA over time. While pest densities may have correlated to natural enemy densities, immunological or electrophoresis studies of gut contents are required to begin to establish a causal link (Kidd and Jervis 1996). Wratten and Pearson (1982), in a study of predation within a New Zealand sugar beet crop, concluded that this lack of information was the biggest drawback to establishing the effect of predation by several natural enemy species on green peach aphid, *Myzus persicae* (Sulzer). Serological work was conducted by Leathwick and Winterbourn (1984) on natural enemy gut contents. They found that over 70% of the four most abundant predators (Pacific damsel bug, ladybirds, Tasmanian lacewing, and European harvestman) gave positive precipitin reactions to lucerne aphid (*Acyrthosiphon* spp.) antiserum. This qualified that these natural enemies fed on lucerne aphids, but did not quantify what impact they were having on aphid populations. These studies in lucerne were conducted during February at a time when low populations of BGLA were found in white clover crops (Chapters 2 and 3; Schroeder and Clifford 1996). Studies similar to Leathwick and Winterbourn (1984), therefore, need to be conducted in white clover seed crops to determine which natural predators are feeding on BGLA, followed by further studies to quantify how many BGLA these species are consuming.

Insecticide effects

Of the insecticides tested for control of BGLA and PM in white clover crops, ladybird larvae were found in significantly lower densities in the lambda-cyhalothrin plots when this insecticide was applied at the recommended field rate of 10 g/ha. A similar result was found with adult ladybird densities in another study by Schroeder *et al.* (1996), where ladybirds were found to be the only natural enemy species to be affected by lambda-cyhalothrin. Rotrekl (1994) also found that 6.25 g/ha lambda-cyhalothrin was particularly toxic to coccinellids. The antifeedant/repellency effect of lambda-cyhalothrin on insect pests could also affect natural enemies like ladybirds, and requires further study. The significant decline in ladybird adult densities in the pirimicarb treatment at 2 DAT (compared with the control) is likely to be a response to low BGLA densities and emigration to an alternative prey source (refer Figure 24, Chapter 4). Pirimicarb is also claimed to be relatively non-toxic to arthropod predators (Wightman & Whitford 1982), although subsequent research revealed that hover fly larvae are particularly susceptible to field rates (100 g a.i./ha) of pirimicarb (Niehoff and Poehling 1995). Pirimicarb toxicity to hover fly larvae was not noted in this study.

Densities of lacewing larvae and adults were significantly lower in the lambda-cyhalothrin-treated plots at 2 and 4 DAT only. However, in preliminary field evaluation work, Schroeder *et al.* (1996) found that adult lacewing populations were not reduced by applications of lambda-cyhalothrin. Lambda-cyhalothrin was applied later (mid December) during that study when BGLA and lacewing numbers were declining naturally, compared with this study with its earlier applications (late November to early December) when BGLA and lacewing densities were increasing. The significant decrease and later recovery of lacewing densities in the lambda-cyhalothrin plots shown in this study support findings from other studies that have shown that lacewings have a high tolerance to some chemicals. Syrett and Penman (1980) found that pirimicarb was 1000-10,000 times more toxic to aphids (*Acyrthosiphon* spp.) than lacewing and ladybird in laboratory tests. Alternatively, lacewing densities may have decreased in the lambda-cyhalothrin treatments in response to low BGLA densities and emigration to an alternative prey source.

Conclusions

The suction sampling method used in this study may have under-estimated the densities of some natural enemy species like lacewing and hover fly larvae. However, this study suggests that the combined effect of the natural enemies does not prevent BGLA and PM nymphal numbers reaching damaging densities in white clover seed crops. This is despite good correlation trends between BGLA and most of the natural enemy densities. Kidd and Jervis (1996) warned that only tentative conclusions may be drawn from correlation analysis and then only when detailed appreciation of the biologies of the species involved was obtained. A lack of any correlation, therefore, does not necessarily discount the effectiveness of a natural enemy species, but may be useful to detect a synchrony with prey populations. Clearly, more intensive field studies are required to quantify the impact of natural enemies on BGLA and PM.

The critical period for insect pest damage in white clover seed crops exists only for a very short time (mid November to late December) when inflorescence development and maturation occurs. Results from this study suggest that if BGLA and PM reach densities causing economic damage then a selective insecticide could be applied either as a prophylactic to provide protection over the critical plant development stage, or as a curative based on economic threshold levels. The impact of the different insecticides on natural enemy numbers appears to be short lived and negligible considering that in most cases their hosts have been eliminated by the insecticides. The response of the predators in such circumstances may be one of emigration to other sources of hosts in other crop areas. Identification of the specific roles of natural enemies in white clover crops would be

enhanced with immunological or electrophoresis studies on gut contents. However, these studies only qualify which host species have been consumed and require further studies to determine the quantitative impact of natural enemies on the hosts.

CHAPTER SEVEN

DISCUSSION

The main aims of the research in this thesis were first, to identify the key economic pests in white clover seed crops by studying the interactions between plant and insect pest phenologies; second, to quantify the effect of selected pests on white clover seed production; third, to determine the most effective timing and placement of insecticide applications for controlling the pests and fourth, to determine the synchrony of potential natural enemy populations with that of the key insect pests.

A preliminary study by Schroeder (1995) showed that potato mirid (PM, *Calocoris norvegicus* Gmelin), bluegreen lucerne aphid (BGLA, *Acyrthosiphon kondoi* Shinji) and brown shield bug (*Dictyotus caenosus* (Westwood)) were the most abundant and, therefore, the most likely key pests found in white clover seed crops. After a more intensive two-season crop monitoring survey (Chapter 2), this conclusion was further confirmed where PM and BGLA were again the most abundant insect pests present at critical times of white clover development. Other potential candidates for pest status of Huia white clover seed crops grown in Canterbury include, brown shield bug, wheat bug (*Nysius huttoni* White) and Australian crop mirid (*Sidnia kinbergi* (Stål)). However, they occurred later in the season and, therefore, would be unlikely to have an impact on early to mid flowering cultivars like Huia. The studies in this thesis have concentrated on the impact of hemipteran pests (especially PM and BGLA) on specific stages of inflorescence development, which are most vulnerable to feeding injury and have the greatest influence on seed quantity and quality. A more intensive monitoring programme (Chapter 3) was conducted within a single Huia white clover seed crop to determine the spatial and temporal distribution of the hemipteran pests and their impacts on inflorescences and seed yields. This study also investigated detailed sampling, which could be used to develop a sampling programme for monitoring and decision making for PM and BGLA.

In previous studies, PM feeding symptoms (Plate 13, Chapter 5) were commonly found in white clover seed crops during inflorescence development, but the impacts of different intensities of PM on inflorescence development and seed yields were not determined. A field cage experiment (Chapter 5) was conducted to determine the impact of different PM densities on white clover inflorescence and seed production and to provide an indication of economic thresholds for use in

seed crops. For PM, a linear response between increasing PM density and decreasing seed yields was shown. Potato mirid feeding was also shown to have a direct effect on reducing inflorescence numbers thereby reducing seed yield. The current practice of applying insecticides to white clover seed crops is largely initiated to control extensive BGLA populations. Because no specific studies on the impact of BGLA feeding on inflorescence or seed production have been carried out a cage experiment, Chapter 5, was also set up to study the impact of high BGLA densities on specific stages of inflorescence development. For BGLA, high densities at different inflorescence growth stages had an indirect effect on seed yields by reducing seed quality (measured by the thousand seed weight).

The control of both PM and BGLA was investigated by determining the optimum time for the application of three insecticides (Chapter 4), while the synchrony of natural enemies commonly found in white clover crops with these two key pests was determined from the largest data set (1994-95 survey) collected during the entire study (Chapter 6).

The following sections are set out to discuss the interactions between both hemipteran pest and white clover plant phenologies, the distribution of the two key pests regionally and within the white clover seed crops, development of a management strategy using insecticides and based on sampling programmes and economic threshold evaluations. Future studies on white clover pest in relation to changes currently taking place in crop management practices are also discussed.

Insect Pest-Plant Phenology Interactions

The importance of understanding the plant's phenology and determining the specific growth stages that are vulnerable to insect damage, and therefore need protecting, have been highlighted in this study and for other crops where hemipteran pests are prevalent. Examples include the relatively long plant developmental period (bud initiation through to seed pod maturation) in which *Lygus* spp. attack lucerne seed crops in Southern Arizona and Southeast California (Stitt 1949) through to a range of 'windows of opportunity' in pistachio nut production in California where several hemipteran pest species caused epicarp lesion injury at different stages of pericarp firmness. Understanding the plant's response to hemipteran feeding injury was highlighted by Clifford *et al.* (1983) in lotus (*Lotus pedunculatus* Cav.) where control of hemipteran pests (mainly PM) was delayed until mid December or when numbers reached 30 mirids/20 net sweeps. Managing the hemipteran pests this way, resulted in feeding damage causing senescence of the apical buds. This resulted in lateral bud development with overall higher flower densities per unit area and a 40%

increase in seed yields compared to plots where hemiptera had been controlled by insecticides earlier in the season. The abilty to compensate for inflorescence loss does not occur to the same extent in white clover, as shown with PM during the cage experiment (Chapter 5) and significantly lower inflorescence numbers in the crop edges where PM numbers were high during the field experiments (Chapters 2 and 3).

If the environmental factors that influence inflorescence development are the same as those that influence insect pest development, it is likely that some degree of synchrony will exist between the two. However, inflorescence initiation by the clover plant is determined by photoperiod (Thomas 1981a). Thomas (1981a) showed that the critical daylength for the long-day reaction was between 12 and 14 hours at 21^{0}C in Huia clover. Therefore, to maximise inflorescence initiation in Huia crops grown in New Zealand, growers manage their crops to achieve peak flowering on the longest day (22 December). Insect development, on the other hand, is often dependent on temperature. Life tables have been used to analyse the effect of time and temperature on population growth rates for many hemipteran pest species including BGLA (Kodet and Nielson 1980; Rohitha and Penman 1983; Poswal *et al.* 1990) and PM (Purcell and Welter 1990). Further studies by Rohitha and Penman (1986a and b) was conducted to determine the effect of environmental factors on BGLA flight periodicity. Such information has been used to construct models to assist in the development of rational control strategies for hemipteran pest (e.g., computer-based advisory model for cereal aphids in Britain by Mann and Wratten (1991)).

In all the current studies, PM nymphs reached their highest density during late November, while BGLA populations peaked two weeks earlier during the 1994-95, in early December, compared with the 1995-96 season. To compare phenologies of crop and insect, crop development measured by flowering patterns would be required. Unfortunately, reliable flowering patterns from the white clover seed crops were not available from the two weekly sampling. While Huia crop development over the season is relatively set, hemipteran development is largely dependent on temperature. For this reason, two approaches were used to determine the effects of PM and BGLA feeding injury on white clover seed production in field cages (Chapter 5). Because PM is univoltine it was released into cages at different densities, while the multivoltine BGLA was released into cages in large numbers at different plant developmental stages (as might be expected with rapid population increases in the field).

Feeding injury

The field cage experiment showed that PM and BGLA had different feeding injury impacts on white clover seed production components. Potato mirid feeding injury had a direct effect on lowering inflorescence numbers (Plates 24 and 25). Similar damage and loss of developing flower buds has been shown to be caused by Australian crop mirids in New Zealand lucerne (Wightman and Macfarlane 1981), several mirid species in birdsfoot trefoil (*Lotus corniculatus* L.) grown in Wisconsin (Wipfli *et al.* 1989) and by green stink bug (*Acrosternum hilare* (Say)) in soybeans grown in the United States (Yeargan 1977; Simmons and Yeargan 1983).

Plate 24. Control cage showing good inflorescence expression.

Plate 25. 'PM 80' cage showing little inflorescence expression. Both photographs were taken (20 December) just before full flowering occurred.

At higher densities, PM survival was reduced in field cages (range 59% 'PM 10' to 15% 'PM 80'), and this was likely to be from competition for a limited food source. Hori and Miles (1993) found that a similar hemipteran pest, green mirid (*Creontiades dilutus* (Stål)), could not complete their development unless it fed on seeds or developing ovules of lucerne. The damage caused by the salivary enzymes of this species caused flower abscission and pod bruising of lucerne, which was

similar to that resulting from PM feeding on white clover inflorescences in this study. The specific pectinases associated with salivary enzymes have not been isolated for PM, but they have been in other mirid species (e.g., Hori and Miles (1993) for green mirid and Martin *et al.* (1988) for cotton fleahopper (*Pseudatomoscelis seriatus* (Reuter)).

Both the early inflorescence loss and later floret senescence caused by PM depended on the maturity of the inflorescence at the time of attack (Figure 49). If florets are attacked at a later stage of inflorescence development the lower florets may complete development and produce seed (Plate 13, Chapter 5). The seed produced from these florets is expected to be of a higher quality and thousand seed weight as a result of better provisioning (Figure 48). This was evident in the field cages where the proportion of inflorescence damage was associated with increasing PM density and an increased thousand seed weight from 'PM 10' to 'PM 40'. However, the highest damage in the 'PM 80' treatments did not result in an increase in thousand seed weight as expected. The main reason for this was because of the severity of inflorescence damage (Plate 25) in the 'PM 80' treatments. The greatest proportion of seed produced from the 'PM 80' treatment was from later occurring inflorescences that were poorly provisioned as the plant switched from reproductive to vegetative growth (Thomas 1981b), forming smaller seed with lower thousand seed weight.

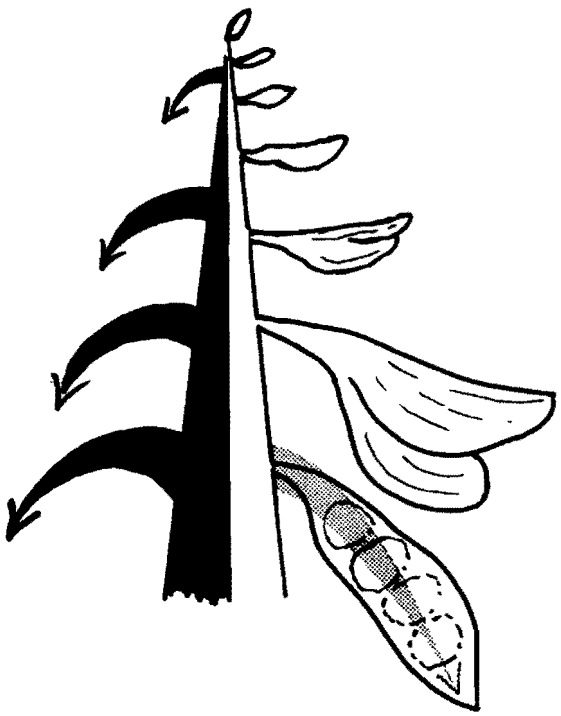


Figure 48. Revised (Schroeder 1995) schematic diagram of a white clover inflorescence showing assimilate partitioning to florets and within florets or developing seed pods. The arrows indicate the 'strength' of provisioning to florets and within florets.

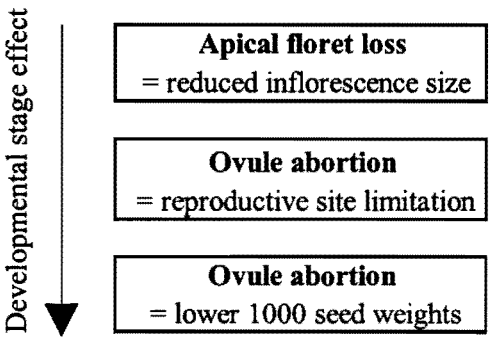


Figure 49. Inflorescence development defects associated with imposed limitations on assimilate for servicing through pest 'theft' (feeding).

While feeding injury caused by PM showed characteristic inflorescence damage symptoms, the symptoms resulting from BGLA feeding were less evident in the field and could be confused with symptoms of water stress. Plant wilting and crop yellowing were typical symptoms observed in white clover seed crops with high BGLA infestations. In the cage experiment there were significantly higher proportions of damaged inflorescences observed in the 'Early-late' and 'Full flower' infestations. This led to some senescence of the apical florets, but the main result of BGLA feeding injury became apparent at harvest when thousand seed weight was significantly reduced. Whereas PM directly affected the density of inflorescences per unit area (refer to Chapter 5), BGLA affected the quality of the resultant seed by removing assimilates from the petiole that are destined for inflorescence and seed provisioning.

In lucerne this damage by BGLA is characterised by stunting of plants and yellowing leaves (Kain *et al.* 1976), caused by BGLA injecting a toxin into plants that causes misshapen leaves and shortened internodes. The effects of BGLA feeding on crop production are not only dependent on the density of BGLA populations, but also the season and the duration of attack. Kain *et al.* (1977) reported lucerne crop production losses of 72%, 47% and 27% attributed to high BGLA populations during autumn, winter and spring (respectively). Plant growth variables like internodal and stolon length should be measured in future work with BGLA in white clover to determine if injected toxins affect plant growth as in lucerne. Measuring plant growth variables also has special relevance for vegetative production of white clover in pastoral systems. In this study, there were indications that heavy BGLA infestations in cages (Chapter 5) resulted in lower vegetative dryweights harvested from each plot. In contrast, there were no significant effects of

PM feeding on plant growth (e.g., shortened internodes) in field cage studies conducted by Schroeder (1995). Subsequently, plant growth measurements were not recorded in this study.

Reduction of thousand seed weight caused primarily by BGLA may have other important effects on white clover seed crop management. For example, successful germination of white clover seed requires scarification and seed that does not germinate is commonly called 'hard seed'. The percentage 'hard seed' content can affect plant density in a crop and add to the soil seed 'bank'. Later cultivation may bring this seed to the soil surface were it will germinate resulting in contamination of a different white clover cultivar crop (Clifford *et al.* 1990). Smaller seed has a smaller surface area available for scarification, therefore, the proportion of hard seed increases with decreasing thousand seed weight (Clifford *et al.* 1990). Buried seed counts are taken prior to a field is accepted for certified seed crops, but rejection of the crop may occur if the volunteer plants are found between rows in subsequent inspections (Seed Certification, Field and Laboratory Standards 1997-1998).

White clover inflorescence damage did not become fully evident until two weeks after the removal of both PM and BGLA from the field cages (Chapter 5). This may mean that feeding injury by these pests is not detected until several weeks later by which time significant seed yield losses could have occurred. A sampling programme that monitors pest densities in the field is required to provide information on which to base control decision-making.

Regional and Field Distributions of PM and BGLA

Development of a sampling and pest management programme requires information on pest distribution. This was determined for PM and BGLA in white clover crops in the main growing regions of Canterbury (Chapter 2) and within a single white clover seed crop (Chapter 3). While, there were significant differences in PM densities recorded each season and between the different growing regions of Canterbury (Chapter 2), the reason for the differences was not determined. In general, PM appeared in white clover seed crops one week later in Timaru (highest latitude) and in Methven (highest altitude). These sites represent the lower extremes in terms of favourable temperature for white clover seed production in Canterbury. While the flowering period is expected to remain constant throughout all the growing regions (because it is based on daylength) changes in temperature caused by latitudinal and altitudinal differences may influence the occurrence of PM in white clover crops. Despite this, little difference between growing regions and their respective temperatures were detected during this study (Figure 4, Chapter 2).

All the fields studied had similar field margins from which PM invaded the crop and it is expected that any given field could experience high PM densities in the crop margins. The main factor influencing PM density would be the number of eggs oviposited in vegetation found in the field verges during the previous summer and the survival of those eggs during the following winter. The stratified (high to low density from crop edge into the crop) distribution of PM within white clover seed crops is similar to what has been found in other studies of PM distributions in other crops (e.g., pistachio nuts grown in California (Purcell and Welter 1990), cereal crops grown in Britain (Moreby 1991), and asparagus grown in the Waikato (Watson and Townsend 1981)). For white clover seed crops, the majority of PM occurred within 4 m from the crop edge.

In general, BGLA was distributed across the whole white clover seed crop. There were significant differences in BGLA densities recorded from the different growing regions in both survey seasons (Chapter 2), but the specific reasons for these differences were not determined. The wider distribution of BGLA within white clover and lucerne (Kain *et al.* 1977) crops is likely to be a result of the method of dispersal each species uses; BGLA flies into the crop, whereas, PM nymphs walk into the crop margins. The fast reproductive capability of BGLA (compared with PM) may also lead to crowding and further dispersal within the crop.

Management of PM and BGLA

PM economic threshold development

When developing an economic action threshold for control of PM nymphs, several variables require consideration. The first concerns the value of the crop which, in the case of white clover seed, is determined by the markets at the end of the season, or before harvest, based on contractual arrangements with a seed merchant. Second, is the area of the crop where PM nymphs occur (predominantly in the first four metres from the edge into the crop). Third, is the cost of pest monitoring (taking the recommended 54 sample units and recording the results) estimated as a minimum of two hours per field at a nominal direct cost charge-out of $25/hour (i.e., $50/field). These costs would require further modification to account for travelling costs, etc. Fourth, is the cost of insecticide(s) and their application. In the exercise below, PM nymph control in an average-sized (8 ha) white clover crop is considered (representing a 0.45 ha area in the 4 m margin) returning $4/kg of seed harvested. Lambda-cyhalothrin applied at the recommended rate costs $25.30/ha with an application cost of $21.00/ha. Total spray cost is approximately $46.30/ha ($21.00/0.45 ha). Therefore, to monitor PM nymphal densities and apply lambda-cyhalothrin for

control in white clover field margins the total cost is $71.30. Two PM density-seed yield equations will be used for the following calculations.

1. From the field cage experiment (Chapter 5):

$$\text{Total seed yield} = 50.4 - 0.34(\text{PM nymph density}) \quad (1)$$

2. From the control plots in the insecticide experiment (Chapter 4):

$$\text{Total seed yield} = 54.2 - 0.38(\text{PM nymph density}) \quad (2)$$

Using equation (1) (where the intercept is expressed as g/m^2) the highest potential yield at a zero PM density is limited to 504 kg/ha and 542 kg/ha using equation (2). The slopes in both equations are similar, suggesting that conditions within the cages resulted in similar seed yield losses to those experienced in the field. Both equations will be used in Table 41. To show expected seed yield losses and gains from control for the 0.45 ha area for varying nymphal densities.

Table 41. Projected seed yield losses caused by different PM nymphal densities using equations generated in the (1) cage and (2) insecticide experiments. Seed yields and cost of control is based on a 0.45 ha area (edge to 4 m crop margin) in an 8 ha white clover seed crop.

	Potato mirid nymph density/m^2							
	0		10		20		40	
Equations used	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Yield (kg/0.45ha)	227	244	212	227	196	210	166	176
Yield loss (kg)	0	0	15	17	31	34	61	68
$ loss at $4/kg	0	0	61	68	122	137	245	274
Cost of spraying	0	0	71	71	71	71	71	71
$ recovered by spraying			-9.8	-2.6	51.4	65.8	173.8	202.6

Application of lambda-cyhalothrin to the crop margin was economically viable at a PM nymph density of $20/m^2$ (Table 41). Differences between the two equations show higher seed yield losses occur from the field-based equation (2). The economic break-even point (where $gains from control implementation equals $costs of control) was at 12 and 11 PM nymphs/m^2 for equations (1) and (2), respectively. Based on the studies done here, this is the lowest population density that will cause economic damage (economic damage is the amount of damage that equals the cost of control, commonly referred to as the economic injury level (EIL) (Stern *et al.* 1959)). Stern *et al.* (1959) proposed the economic threshold (ET) as the operational decision rule where control measures should be implemented to prevent an increasing population from reaching the EIL. The ET is also referred to as the action threshold by some entomologists (e.g., Yencho *et al.* 1986). During the 1994-95 season only Southbridge recorded PM nymphal densities that were less than $10/m^2$ in the crop margins, whereas only Methven and Timaru recorded densities above $10/m^2$

during the 1995-96 season. A suggested action threshold for insecticide application to control PM nymphs in white clover seed crop margins would be 10/m^2 allowing for maximum egg emergence to take place as most insecticides do not have ovicidal activity. Therefore, it is economically beneficial that monitoring of this pest occurs in all white clover seed crops. The calculations used here can be modified to account for changing seed yield returns, insecticide costs and field dimensions as required (with the economic benefit of controlling PM reducing with smaller field sizes).

PM sampling programme

Analysis in the previous section showed that if PM nymph densities exceeded 12/m^2 insecticide control was economically viable in the 4 m crop margin. To obtain a reliable estimate of the mean densities of PM nymphs (± 20%), 54 sample units or pottles (each consisting of 10 suctions covering 0.2 m^2) taken at random positions in late November, and 13 pottles in early December (Chapter 3) are required in the 4 m crop margin. Because PM is univoltine, it is necessary to sample the fields only once the nymphs have emerged from the eggs, but before main inflorescence development occurs. For Huia crops this criterion is met when the crop is at approximately 5% flowering. Assuming PM cause similar seed yield losses in other white clover cultivars, modifications to the above recommendations may be: 1) for cultivars that flower earlier than Huia (e.g., Grasslands Pitau) sampling should also begin at 5% flowering, and insecticide applied when PM densities exceed 10/m^2. If this density is not met sampling should continue on a weekly basis until PM nymph numbers either reach the threshold or the crop has reached full flower. For later flowering white clover cultivars (e.g., Tillman) one sample at 5% flowering should be all that is necessary as nymph emergence and movement into the crop should be completed by this time.

Implications arising from PM control programme

The preceding discussion has demonstrated that control of low densities of PM nymphs is economically viable in the 4 m crop margin. However, this area often has the poorest soil structure, highest weed density and poorest white clover plant growth of the whole crop. Soil compaction from stock and vehicles, over or under irrigation and poor fertiliser application also contribute to poor plant growth in this area. The main cause for the down-grading of clover seed is often due to high weed seed contamination from this area. In fact, a higher priority is placed on weed control in white clover crops than insect pest control (Greg Sparks pers. comm., white clover

crop certification field inspector). If the seed from this commonly weedy area is included in the bulk crop seed line, heavy dressing-out penalties are incurred and/or the seed line may be rejected and downgraded resulting in lower returns to the farmer. Farmers overcome this problem by either mowing the crop margins, not harvesting the area, or harvesting the crop margins as a separate seed line (Greg Sparks pers. comm.). Mowing the field margins may force PM nymphs further into the crop in search of developing inflorescences, while leaving the margins may act as a 'trap-crop' reducing this invasion. The importance of PM in white clover seed crops could, therefore, be dependant on field management practice adopted by the grower.

BGLA economic threshold development

While high BGLA populations caused inflorescence damage and significantly reduced seed quality (as measured by the thousand seed weight) no clear/consistent relationship between BGLA density and seed yield was established in the field cage experiment (Chapter 5) and insecticide experiment (Chapter 4). The highest white clover inflorescence damage and lowest thousand seed weight occurred with high BGLA populations in the field cages ('Early-late' and 'Full flower' infestations). The following assumptions for BGLA threshold development are based on recommendations from other studies of BGLA in white clover seed crops and are given as a general guide. Trought (1977) found that 4 BGLA/inflorescence caused no significant effect on seed yield, but 20% seed yield loss occurred if numbers were over 16/inflorescence. Because of rapid population build-up, Trought and Batey (1980) later recommended insecticide application when BGLA exceeded 2/inflorescence. With some modifications this intensity estimate-based threshold can be converted to an absolute estimate (per m^2). There are two main factors to be considered in the development of a BGLA threshold. First, is the rapid developmental rate of BGLA. In one of the field cage treatments, there was a 40-fold increase in BGLA numbers over four weeks. During the 1994-95 survey season the average increase over two weeks (mid to late-November) was over 400%, whereas during the 1995-96 survey an increase of 2.4-fold in BGLA populations occurred. Second, is the interval between sampling of white clover crops. If the crop is visited weekly, as is common with professional crop monitoring practices, then the threshold should be set at the lower 2 BGLA/inflorescence to accommodate the potential for rapid population increase between visits. If an individual farmer does crop monitoring more frequently, then the higher threshold of 4 BGLA/inflorescence may be used.

BGLA sampling programme

To obtain a reliable estimate of the mean BGLA densities (± 20%), 15 to 17 sample units or pottles (each consisting of 10 suctions covering 0.2 m^2) taken from randomly selected positions in the crop are required (Chapter 3) during the late-November to early-December period when BGLA populations were greatest.

To convert an intensity threshold of BGLA/inflorescence to an absolute estimate threshold an estimate of the inflorescence numbers/m^2 is required. Development of a sampling method to determine a reliable estimate of inflorescence density requires further investigation. The action threshold (number aphids/m^2) can be easily calculated once the estimate of inflorescence density is established by multiplying the estimated inflorescence density by two or four (the aphid intensity thresholds). If the BGLA density exceeds these thresholds then application of an insecticide is recommended. Sampling of white clover crops should commence when flowering starts through until BGLA populations decline (approximately two weeks after full flowering when seed is setting).

PM and BGLA Control

Insecticide control

The application of chemicals on white clover seed crops in New Zealand is currently unrestricted although the use of registered products is encouraged. This study suggests the use of lambda-cyhalothrin or fluvalinate (although not as effective against PM and BGLA) as a prophylactic application to protect the vulnerable inflorescence stages. Application of an insecticide is recommended only when the crop has reached 5% flowering. As most farmers are not sufficiently familiar with the common insect pests they generally prefer to use recommendations based on the crop phenology (e.g., percentage flowering as used here). An extension publication (Schroeder 1998) produced by the Foundation for Arable Research[9] (Appendix C.) has recently been distributed to most white clover growers in Canterbury. The aim of the publication was to clearly outline the insect pest problems associated with spring and summer growth of white clover and their effects on seed production derived from studies presented in this thesis. If future restrictions are imposed on chemical usage in white clover seed crops this information combined with the

sampling programme previously outlined would need to be implemented to justify chemical application. The use of an action threshold based on the level of infestation rather than on a calendar basis, may reduce the number of insecticide spray applications, or at least ensure that the number of applications are economically viable (Dent 1991).

The present studies have addressed seed production losses based on individual pest species (PM and BGLA). However, both species are found in white clover seed crops at the same time. The combined effects of both pests requires investigation to determine whether a multi-pest threshold should be developed based on the combined feeding interactive effects on white clover seed production. The relationships (e.g., cumulative) between PM and BGLA could be evaluated in field cages, where different factors (e.g., PM densities) could be isolated.

Biological control

Although some natural enemy populations appear to be well synchronised with BGLA (e.g., ladybird and lacewing) and PM nymphs (e.g., European harvestman), they were unable to prevent pest densities increasing to EIL (Chapter 6). The impact of the insecticide applications on natural enemy populations was shown to be negligible and, in most cases was limited to a short period (e.g., the effect of lambda-cyhalothrin on ladybirds). Of the natural enemies commonly found in white clover seed crops, all have been reported to feed on aphids, while none has been reported to feed on PM. This suggests further study is needed involving gut content dissections or serological analysis to determine whether PM are preyed upon by different natural enemies. Until such studies establish these associations, the use of alternative controls for PM is recommended.

By contrast, the control of BGLA by natural enemies could be enhanced by several methods (e.g., inundative release and provision of trap crops). The effects of an inundative release of the aphid parasitoid *Aphidius eadyi* Stary Gonzalez and Hall for lucerne aphid control was studied by Cameron *et al.* (1983), who found that the slow dispersal of the parasitoid reduced its impact. Leathwick (1989) concluded that aphid parasites were not contributing significantly to aphid mortality in lucerne stands. Trap crops for increasing hover fly larvae in winter wheat crops have been investigated by Lövei *et al.* (1993), but the use of trap crops in white clover is not practical given the special establishment and management required. The white clover crop margin itself

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[9] The Foundation for Arable Research is funded through levies collected from seed crops. It represents the farmer body and funds contractual research based on farmer needs.

already acts as a trap crop for pests like PM, so there would be little advantage gained by establishing a specialist trap crop.

Cultural control

Several crop management practices have been used to effectively reduce the numbers of both PM and Australian crop mirids in asparagus crops (Townsend and Watson 1982). These include the removal of stubble carrying the eggs, or by enhancing its breakdown by soil incorporation during winter cultivations. The same results could possibly be obtained in white clover seed crops through the heavy grazing of sheep before closing for seed production. Control of weeds around the crop verges by herbicide application is unlikely to decrease the reservoir of PM eggs unless the vegetation is removed, burnt or incorporated into the soil.

Control of BGLA in lucerne crops has largely been achieved through the breeding of resistant cultivars, but there is currently no selection for BGLA or PM resistance in the New Zealand white clover breeding programme. There are also major differences between lucerne and white clover growing practices. First, lucerne is grown mainly as a pure-stand, forage crop in New Zealand from which seed may or may not be harvested, while forage white clover is one of several plant species in most New Zealand pastures. White clover's contribution to total pasture yield is estimated at 20% (Caradus *et al.* 1996). The only time white clover is grown as a monoculture is when it is grown for seed. The relatively high value of this cash-crop means insecticide applications are economically viable for the control of hemipteran pests. Bluegreen lucerne aphid and PM are not, currently, considered major pests of pasture and there have been no studies of the impacts of BGLA or PM on the vegetative production of white clover in pastures. Different white clover cultivars have been screened for resistance against redlegged earth mite (*Halotydeus destructor*) (Marshall *et al.* 1997) and a substantial breeding programme is currently being conducted on resistance to root-knot nematode (*Meloidogyne* spp.), a widespread white clover pest in New Zealand pastures. Grasslands Prestige has shown greater resistance to lucerneflea (*Sminthurus viridis*), stem and root nematode (*Ditylenchus dispaci*) and clover rust (*Uromyces trifolii*) than the other New Zealand white clover cultivars but less resistance to slug damage than Grasslands Tahora (Caradus and Woodfield 1997). A more recent insect pest (clover root weevil, *Sitona lepidus* Gyllenhäl), first found in Waikato pastures in 1996 (Barratt *et al.* 1996), has significantly reduced the white clover component of pastures in this area with reports of total white clover loss from pastures. Clover root weevil is presently restricted to some growing regions in the North Island, but is spreading and has the potential to be a major pest wherever white clover is

grown in New Zealand. This may encourage plant breeders to screen for resistance factors or use other plant breeding techniques (e.g., transgenic plants).

It is possible that some white clover cultivars may express tolerance or resistance to hemipteran pest feeding. For example, white clover cultivars are presently being graded by their level of cyanide production and those with high cyanide levels have been shown to resist field slug feeding. A simple field experiment including a wide range of cultivars may reveal those less preferred by insect pests. These, in turn, could be studied more closely to determine the mechanism(s) involved, and whether the resistance mechanism would limit damage.

Future Studies

The impact of PM and BGLA feeding injury on inflorescences and seed yield has been the main focus in this study. Seed yield components (e.g., florets per inflorescence, seeds per floret) require further study to fully understand the impacts of pest feeding injury. An in-depth study of hemipteran feeding could include tagging different stages of inflorescence development through the season and dissecting them at harvest to determine the effect on the numbers of florets per inflorescence and number and weight of seed per floret. This would demonstrate whether the plant compensates for injury by PM or BGLA. Because it may not be possible to determine which insect species had fed on the inflorescence in the field a specific study would be required to investigate these factors. Such a study could be carried out by caging known numbers (and developmental stages) of each pest on specific plant parts at different stages of inflorescence development for given times. An experiment using clip cages (Plate 26) to isolate third instar PM nymphs and different BGLA intensities was attempted during the 1996-97 season using clonal white clover plants in the field (Schroeder unpublished). However, the final results were not processed as symptoms similar to PM feeding injury also occurred on the non-caged inflorescences (PM nymphs were observed walking from the neighbouring field verges into the experimental site and feeding on the test plants). To overcome this problem, future experiments should be conducted in an insect-free environment, such as in a cage or tunnel house supplied with bees for pollination. Clip cage studies could also include an investigation of the effects of pest feeding at the stolon tip, which, with inflorescence development, represents the vegetative growth of white clover. If stolon tip damage caused by insect feeding injury occurs early in the season, this would have particular implications in relation to reduction of both inflorescence and seed production as well as pasture production. Whether or not the plant compensates for such damage could also be studied. The use of clip cages assumes that heavy damage occurs within a short time rather than

the gradual build-up corresponding to the population development of the pest in the field. Interpretation of results from clip cage studies would, therefore, need to be done with caution.

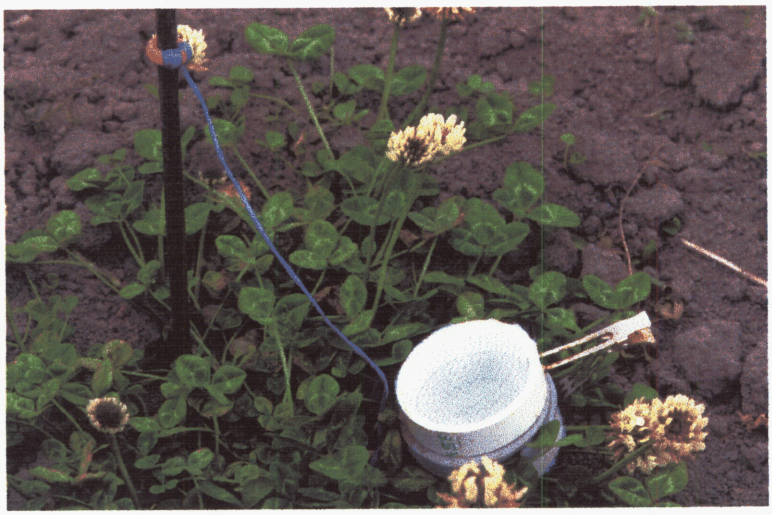

Plate 26. Small clip cage used in preliminary experiment to evaluate the effect of PM and BGLA on specific parts of white clover plant.

Changes in white clover growing practices

All the experiments conducted during this study used 'first-harvest' Huia seed crops. The area of Huia crops has been decreasing over recent years as more farmers switch to growing more lucrative proprietary cultivars. As outlined in the Introduction (Chapter 1), these proprietary cultivars cover a range of different flowering types and other growth habits. In a preliminary field experiment conducted by Schroeder and Clifford (1998 unpublished), three white clover cultivars were established in field plots to study the impact of insect pest damage on a range of different flowering types. Huia represented the 'normal' flowering cultivar with Grasslands Pitau and Tillman being early and late flowering cultivars, respectively. Each plot was split as a paired plot design (control and lambda-cyhalothrin treated) of which there were five replicates for each cultivar. Heavy infestations of BGLA occurred in the control plots. Preliminary results showed that Pitau was adversely affected by BGLA feeding injury, which was reflected in a significant ($P< 0.001$) reduction in seed yield and thousand seed weight between the control and treated plots. The main flowering period for the Tillman cultivar occurred after the BGLA population had peaked and decreased to low densities. This cultivar, however, was still flowering when Australian crop mirid numbers were increasing and it is likely that this pest would cause injury to the developing inflorescences. These limited results suggest that further study is required to determine the impact of hemipteran pests in a range of different white clover cultivars as it appears that each may be affected differently and injured by different key pests. Furthermore, studies over several seasons would be needed to account for seasonal variations.

The insect pest fauna over several successive years may increase as residual numbers build up from year to year. The potential for residual build-up of pest populations requires verification by field experimentation and necessary changes to the pest management programme. With the successful control of clover casebearer moth by the two introduced parasitic wasps (Pearson 1982) more farmers are taking successive harvests from the same crop. The current seed certification requirements are as follows:

'Breeders' seed may be taken for one harvest and then down-graded to 'Basic' for the following three harvests.

'Basic' seed may be taken for two harvest seasons and then down-graded to 'First Generation' for the following two harvests (MAF Seed Certification 1997-1998 Field and Laboratory Standards).

Conclusions

The main aims of the research in this thesis were first, to identify the key economic pests in white clover seed crops by studying the interactions between plant and insect pest phenologies; second, to quantify the effect of selected pests on white clover seed production; third, to determine the most effective timing and placement of insecticide applications for controlling the pests and fourth, to determine the synchrony of potential natural enemy populations with that of the key insect pests.

Potato mirid and bluegreen lucerne aphid were the key hemipteran pests found in Huia white clover seed crops grown in Canterbury. High numbers of both species occurred during inflorescence development in spring. The impact of high potato mirid numbers (predominantly found in the crop's margin) significantly reduced inflorescence density and increased inflorescence damage resulting in seed yield losses from these areas. High bluegreen lucerne aphid populations caused inflorescence damage and significantly reduced seed quality (measured by the thousand seed weight). The best control of both hemipteran pests would be achieved by insecticide application based on economic injury levels and action thresholds developed during the study. Of the insecticides studied, lambda-cyhalothrin and fluvalinate reduced both potato mirid and bluegreen lucerne aphid numbers for up to three weeks, while pirimicarb reduced only bluegreen lucerne aphid populations. For the seasons investigated in this thesis, high numbers of natural enemies occurred too late or were too few to control potato mirid and bluegreen lucerne aphid population build-up. Findings from this study require further field investigation and modification for use in other white clover cultivars and successive harvest crops.

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APPENDICES

APPENDIX A

Survey Crop Soil Types and Attributes (Chapter 2)

Growing Region	Soil Type	Attributes	Irrigated?
Ashburton/Barrhill			
Foster	Wakanui shallow silt loam	Excessively drained, summer drought	✖
Irwin	Barrhill fine silt loam	Well drained, seasonally droughty	✖
MacFarlane	Barrhill fine silt loam		✖
Coastal Ashburton			
Bennett	Wakanui silt loam	Imperfectly drained and subject to	✓
Wilson	Wakanui silt loam	waterlogging	✓
Digby	Temuka silt loam on clay loam		✓
Darfield			
Adams	Lismore stony silt loam	Excessively drained, stony subsoils	✖
Gillanders	Lismore stony silt loam	subject to summer droughts and wind	✖
Gilmour	Lismore stony silt loam	erosion	✖
Lincoln			
Bussell	Templeton silt loam on a	Well drained, droughty in summer	✖
Morrish	sandy loam	Well drained, droughty in summer	✖
Macartney	Taitapu silt loam on a clay loam	Poorly drained, waterlogging in natural state	✓
Methven			
Coppard	Lyndhurst silt loam	Somewhat excessively drained,	✓
Ridge	Lyndhurst silt loam	seasonally droughty	✓
Wright	Lyndhurst silt loam		✖
Sheffield			
Cullen	Lyndhurst silt loam	Somewhat excessively drained,	✖
Earle	Lyndhurst silt loam	seasonally droughty	✖
Jenkin	Lyndhurst silt loam		✖
Southbridge			
Heslop	Paparua sandy loam	well drained, seasonally droughty	✓
Lemon	Paparua sandy loam		✓
Lowery	Paparua sandy loam		✓
Timaru			
Howey	Templeton silt loam	well drained, occasionally droughty	✖
Kelliher		in summer	✖
White			✖

Soil descriptions source: Kear *et al.* 1967.

APPENDIX B

1995-96 White Clover Grower Survey (Chapter 2)

Growers Name:.....

Size of field sampled:.....

Irrigated or Dryland (delete one)

Previous crop:.....

Huia grown as: Row spaced or Broadcast (delete one)

Sowing rate:.....

Main weeds in crop:.....

Herbicides used:.....

Insecticides used (rates and dates of application):.....

.....

Reason for use:.....

Did you apply the insecticide over the field sampling positions? Yes or No

If No, what buffer zone did you leave around the pegged area?.....

Total seed yield from field (kg):..... Dressed or Undressed (delete one)

Rank from 1 (highest importance) to 6 (lowest importance) your decision making preferences when applying insecticides in white clover seed crops.

(25) It has registration to control the target pest in white clover seed crops.

(35) Past experience with this insecticide gave good results.

(28) The cost of the chemical and it's application.

(11) The selectivity of the insecticide (i.e., controls the pests, but doesn't harm the honey bees or beneficial insects like ladybirds.

(32) The chemical has good residual control of pests.

(23) The chemical is relatively safe to the user.

What information helps you to make your current insect pest management decisions?

.....

.....

What information would help your decision making easier?.....

.....

APPENDIX C

Foundation for Arable Research Publication

Foundation for Arable Research
PO Box 80, Lincoln

Ph 03 325 6353
Fax 03 325 6354

FAR
Arable Update

HERBAGE

No.6 November 1997

Potato mirid biology and control

Compiled by Neil Schroeder, AgResearch

Host Plants

Potato mirid (*Calocoris norvegicus*) are distributed throughout NZ and have been associated with damage to asparagus in the Waikato, lotus, lucerne, white clover and red clover in Canterbury, and many other vegetable and legume seed crops.

Life History

Potato mirids normally have 1 life cycle per year. Eggs are laid in vegetation during late summer and emerge as nymphs in early to mid November in Canterbury.

Nymphs go through 5 developmental stages (instars). The first and second instars are very small (<2 mm) and can be mistaken for aphids, although they have well developed legs, run faster and tend to be a brighter green than aphids.

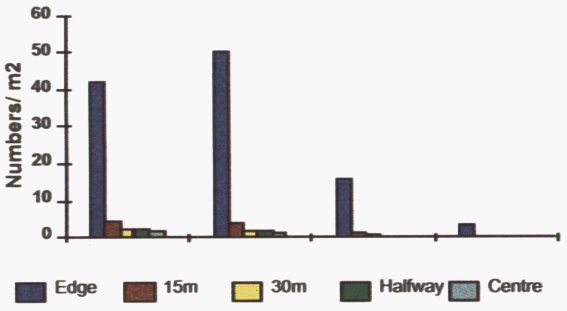

Figure 1. Distribution of potato mirid nymphs in 24 Canterbury white clover crops (1994-95 season).

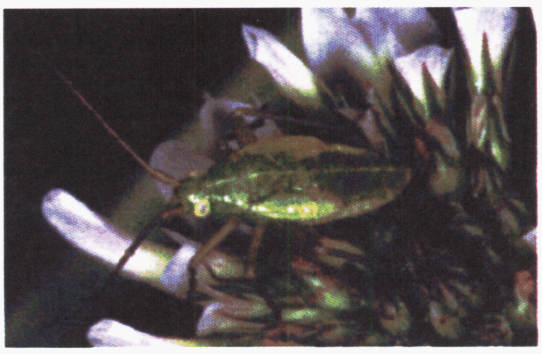

Plate 1. Potato mirid fifth instar nymph (note wing pads).

Later instars are characterised by the developing wing pads (Plate 1). Nymphs invade from refuges around the crop margins and can be found in large numbers at the crop edges in mid November to mid December. Their numbers decrease from the edge into the crop (Figure 1).

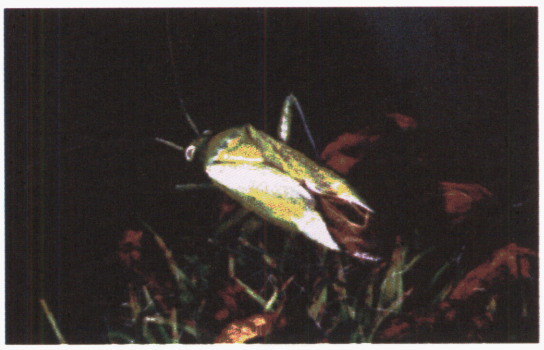

Plate 2. Potato mirid adult.

Plate 3. Early flower bud injury caused by potato mirid feeding. This bud has been destroyed.

Plate 4. Typical inflorescence injury - the youngest florets have been destroyed but lower florets will produce seed.

Foundation for Arable Research
PO Box 80, Lincoln

Ph 03 325 6353
Fax 03 325 6354

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Arable Update

HERBAGE

No.7 November 1997

Bluegreen lucerne aphid biology and control

Compiled by Neil Schroeder, AgResearch

Background

Host Plants

Bluegreen lucerne aphid (*Acyrthosiphon kondoi*) prefers white clover, lucerne, lotus, and other herbage legumes.

Life History

Bluegreen lucerne aphid prefers cooler temperatures with peak numbers occurring in early to mid December in Canterbury white clover crops. A later, lower peak occurs in autumn. Adults are 2-3 mm long at maturity.

No sexual forms of bluegreen lucerne aphid have been recorded in New Zealand, so all are females and produce offspring parthenogenetically. Winged forms occur during peak numbers and disperse from the crops when temperatures increase and host plant food quality decreases (refer Plate 1).

Bluegreen lucerne aphid overwinter on lucerne and other pasture legumes. Under ideal field conditions, populations can build up rapidly from 10 to 500 aphids per lucerne stem in 1-2 weeks. Their distribution is more uniform throughout the whole crop compared with potato mirid, which is more abundant in the margins.

Feeding Damage

Plant damage is caused by all life stages through the injection of salivary enzymes into soft plant parts (developing buds, inflorescences, stolon tips and young leaves). This causes plant stunting and yellowing of leaves. High populations of bluegreen lucerne aphid will enhance the effect of moisture stress on white clover plants. This can shorten the white clover flowering season, especially in light and non-irrigated soils.

Detection

Bluegreen lucerne aphids can easily be detected by shaking clover foliage onto a piece of white paper or into the hand. They are blue-green in colour and the body surface texture is somewhat waxy. They are slow walkers. Flights of bluegreen aphid may be detected by placing yellow sticky traps just above crop height in the field and monitoring the numbers collected. Sticky traps are usually available from horticultural supply companies.

Yield Losses

Bluegreen lucerne aphid may reduce inflorescence numbers per unit area by heavy feeding on young buds. However, they are generally associated with reductions in seed quality as shown in Table 1.

In a field cage experiment, infestation of bluegreen aphids (mixed age populations) at 200 per plant during first (2nd half November) and second (1st half December) clover inflorescence development did not result in increases in aphid numbers over a two week period, but infestation at full flower (2nd half December) meant numbers increased from 1200/cage to 2826/cage.

The effect of these populations can be seen in the resultant seed size (measured by thousand seed weight) and yield shown in Table 1.

Table 1. White clover seed yields (kg/ha) and thousand seed weights (g) following bluegreen lucerne aphid infestation at different plant developmental stages in isolation cages for two weeks.

	Control	Time of infestation		
		First Flower	Second Flower	Full Flower
kg/ha	316	306	285	221
TSW	0.661	0.653	0.654	0.618*

* significantly ($P < 0.001$) lower than control TSW.

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No.7 November 1997

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TSW	0.661	0.653	0.654	0.618*

* significantly ($P < 0.001$) lower than control TSW.

In contrast, when fifty winged adults (to simulate an incoming aphid flight) were placed in cages at first flower development numbers reached 2082 after 4 weeks. These large numbers resulted in a seed yield of 266 kg/ha and TSW of 0.614, a large decrease compared with the aphid-free plots in Table 1.

Bluegreen lucerne aphid is also a vector for several important plant viruses which may decrease white clover production, especially in second year crops.

Cultural Control

While there are some lucerne cultivars available which have resistance to bluegreen lucerne aphid, there has been no work done on white clover to determine if there are any characteristics that give plant resistance. Because of their invasion flights and rapid population increases, there are no cultural control strategies currently available for bluegreen lucerne aphid in white clover crops.

Plate 1. A colony of bluegreen lucerne aphids on a white clover stem (note both winged and non-winged forms present). (© Neil Schroeder Photography)

Biological Control

There are a range of biological agents that can collectively cause large bluegreen lucerne aphid mortalities (refer to Arable Update, Herbage No.9). The *Entomophthora* fungus, which infects aphid populations during cool, humid conditions is the natural biological control which causes the largest decrease in aphid numbers.

Ladybirds, lacewings, syrphids and nabids prey on aphids in late spring and through the summer. Several parasites have also been introduced, but their impact on aphid numbers has not been determined in white clover crops.

Chemical Control

There are several insecticides which are effective against bluegreen lucerne aphids in white clover crops.

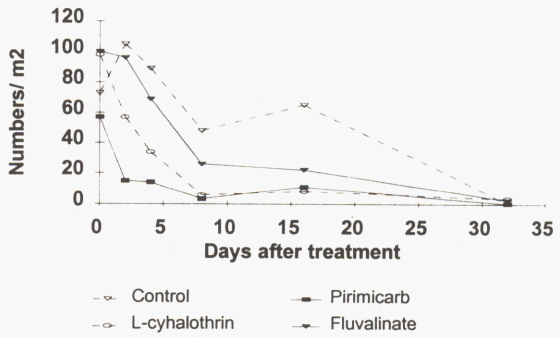
- **Fluvalinate** (36 g a.i./ha) (Mavrick Flo®) is a synthetic pyrethroid registered for use against aphids in white clover crops. It did not give the quick knock-down in aphid numbers like pirimicarb.

- **Lambda-cyhalothrin** (10 g a.i./ha) (Karate®) is a synthetic pyrethroid currently awaiting full registration for use in white clover crops. It gave the second best control of bluegreen aphid in the experiment.

- **Pirimicarb** (125 g a.i./ha) (Pirimor®) is a carbamate and a specific aphicide. It gave the quickest aphid knock-down and good residual effects in the experiment.

In a field spray experiment conducted in three white clover crops during the 1996-97 season three insecticides were evaluated. Their effects on bluegreen lucerne aphid are shown in Figure 1.

Figure 1. Bluegreen lucerne aphid numbers before and after insecticide application at the end of November 1996.



Other products

- **Dichlorvos** (200 g a.i./ha) (Nuvan®) is a short lived insecticide which requires warm, still conditions to maximise its contact/fumigant action. Registered to control clover case bearer moth.
- **Maldison** (175 g a.i./ha) (Malathion) is a fast-acting, short residual insecticide which is registered for control of Lucerne flea in clover.

APPENDIX D

The Effects of Insecticides on Wheat Bug and Lucerneflea (Chapter 4)

Wheat bug adults

There was a significant (P< 0.001) difference in the pooled mean of wheat bug adults collected between the three fields for the duration of the experiment. When numbers reached a maximum around 32 DAT (Figure 1) wheat bug adult numbers ranged from 12 to 4/m^2 (P< 0.001) in the Heslop and Macartney fields, respectively.

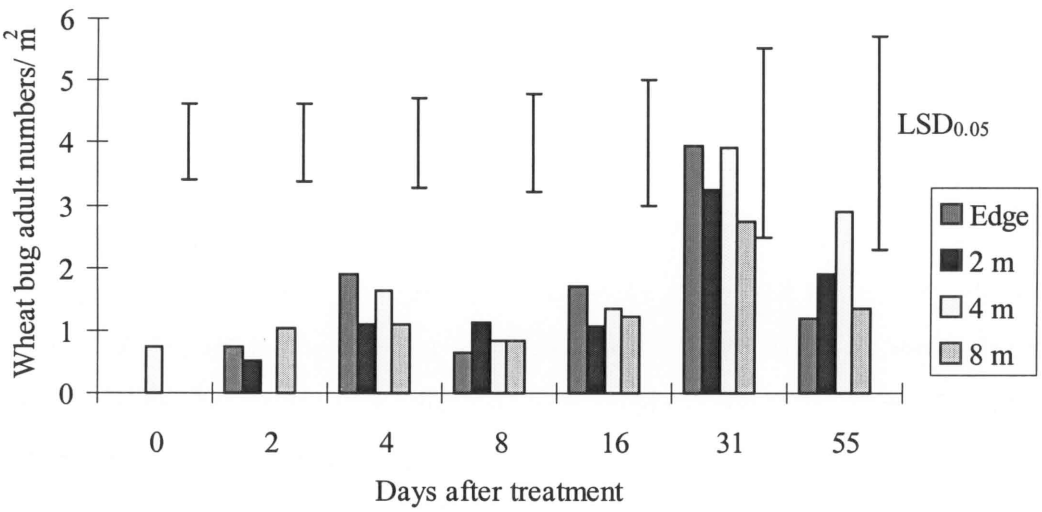


Figure 1. Wheat bug adult numbers (square root transformed) and distribution collected in white clover fields from the 'double application' control plots prior to and after treatment.

Wheat bug numbers were uniform and not significantly (P> 0.05) different between sampling positions at each of the sampling dates (Figure 1). Maximum wheat bug adult numbers were reached at 31 DAT in the double application control treatments and ranged from 16 to 7/m^2 in the edge and 8m positions, respectively.

Table 1. Square root transformation (and back-transformed) mean density (number/m^2) of pooled application timings for wheat bug adults collected before and after spray treatment in white clover seed crops. Results are given for pooled 'edge', 2, and 4 m positions only.

	Days after treatment					
	pre	2	4	8	16	32
L-cyhalothrin	0.9 (0.8)	0.9 (0.8)	2.2 (4.8)	1.5 (2.3)	2.4 (5.8)	3.2 (10)
Fluvalinate	0.8 (0.6)	1.1 (1.2)	1.5 (2.3)	1.3 (1.7)	2.0 (4.0)	2.9 (8.4)
Pirimicarb	0.6 (0.4)	0.9 (0.8)	1.2 (1.4)	1.6 (2.6)	1.6 (2.6)	2.9 (8.4)
Control	0.4 (0.2)	0.8 (0.6)	1.4 (2.0)	1.4 (2.0)	1.5 (2.3)	2.0 (4.0)
$LSD_{0.05}$	0.5	0.6	1.1	1.0	0.6	0.7
L-cyhal v Control	*	ns	ns	ns	**	**
Fluvalinate vs Control	ns	ns	ns	ns	ns	*
Pirim v Control	ns	ns	ns	ns	ns	*

ns = not significant, * P< 0.05, ** P< 0.01

Overall, there were no significant (P> 0.05) reductions in wheat bug adult numbers from any of the chemical treatments applied. There were, however, significant (P< 0.01) increases in overall numbers recorded in the lambda-cyhalothrin treatments at 16 and 32 DAT and (P< 0.05) fluvalinate and pirimicarb treatments at 32 DAT (Table 1).

When the application numbers were pooled there were no significant (P> 0.05) differences in the of wheat bug adult density across the sampling positions within treatments at each sampling date.

None of the chemical treatments significantly (P> 0.05) decreased the numbers of wheat bug adults at any time in any of the three applications.

Lucerneflea

The pooled lucerneflea numbers were significantly (P< 0.001) higher in the Macartney field compared to the Heslop and Lowery fields for the duration of the experiment. The highest overall numbers collected from the Macartney field was 30/m^2 compared with 0/m^2 at Heslops.

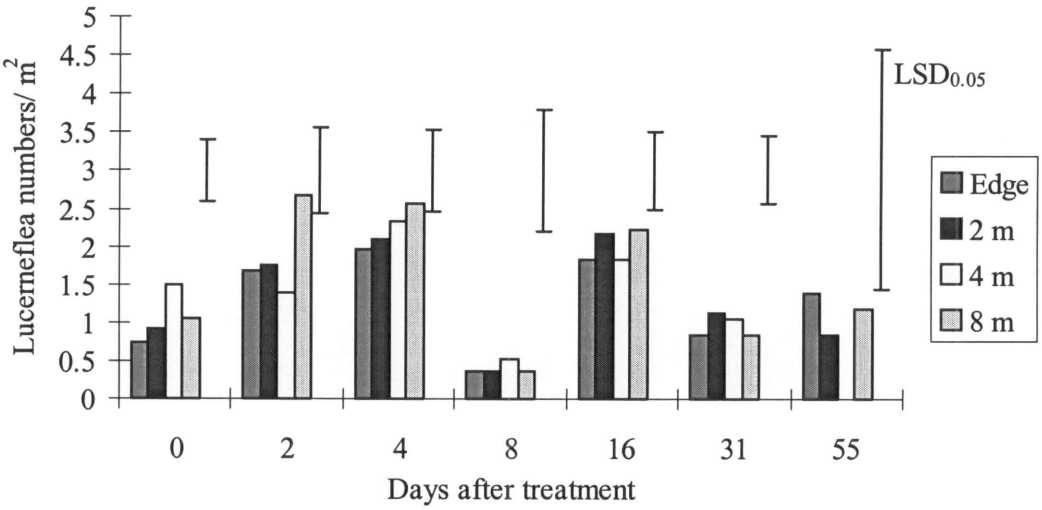


Figure 2. Lucerneflea numbers (square root transformed) and distribution collected in white clover fields from the 'double application' control plots prior to and after treatment.

Lucerneflea numbers were uniform and not significantly (P> 0.05) different between the sampling positions at each of the sampling dates (Figure 2). Overall lucerneflea numbers remained relatively constant over the experimental period.

Table 2. Square root transformation (and back-transformed) mean density (number/m^2) of pooled application timings for lucernefleas collected before and after spray treatment in white clover seed crops. Results are given for pooled 'edge', 2, and 4 m positions only.

	Days after treatment					
	pre	2	4	8	16	32
L-cyhalothrin	0.6 (0.4)	1.4 (2.0)	1.6 (2.3)	2.1 (4.4)	2.1 (4.4)	2.4 (5.8)
Fluvalinate	1.4 (2.0)	1.5 (2.3)	1.7 (2.9)	2.1 (4.4)	2.2 (4.8)	1.7 (2.9)
Pirimicarb	0.9 (0.8)	1.3 (1.7)	1.8 (3.2)	1.8 (3.2)	1.3 (1.7)	1.0 (1.0)
Control	1.0 (1.0)	1.2 (1.4)	1.5 (2.3)	1.7 (2.9)	1.4 (2.0)	1.0 (1.0)
$LSD_{0.05}$	1.1	0.5	1.1	0.5	1.6	1.9
L-cyhal v Control	ns	ns	ns	ns	ns	ns
Fluvalinate vs Control	ns	ns	ns	ns	ns	ns
Pirim v Control	ns	ns	ns	ns	ns	ns

ns = not significant

None of the chemicals significantly (P> 0.05) reduced lucerneflea numbers below those collected in the control treatments at each sampling date (Table 2). There were no treatments which significantly (P> 0.05) changed the uniform distribution lucernefleas within plots at each sampling date when application numbers were pooled.

None of the chemical treatments significantly ($P > 0.05$) decreased the numbers of lucernefleas at any time in any of the three applications.