Orchard habitat management to enhance IPM systems

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VIC Department of Primary Industries

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Final Report for HAL Project AP 00033 (February 2005)

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Department of Primary Industries - Victoria

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Final report for HAL project AP00033

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Scope of the Report
This report presents the key findings and a summary of the glasshouse and field studies conducted in Victoria from July 2000 to September 2004 by the Project team. It also includes information to report on milestone 8 (technology transfer of key results).

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Peter Ridland (project leader from September 2003)
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Media Summary

Effective integrated pest management (IPM) programs for pome fruit crops require sufficient numbers of the natural enemies of pest species to be present in the orchard at the appropriate time.

Even when selective insecticides that are relatively harmless to these beneficial insects are used, commercial apple and pear orchards can be inhospitable places for them because of a lack of food (nectar, pollen or alternative prey) and shelter.

To address this problem, a range of flowering plants were grown as cover crops in commercial orchards to assess their effects on the colonisation and performance of beneficial insects, which include lacewings, ladybirds, hover flies and wasp parasitoids.

Initially, potential cover crops were identified through a desktop study of world scientific literature on conservation biological control and habitat manipulation.

Twenty-two plant species were then tested in the glasshouse to determine their susceptibility to light brown apple moth (LBAM), a major pest of pome fruit crops. The most promising candidates were buckwheat, white mustard, chicory, yarrow, fennel, Queen Anne's lace, *Phacelia*, borage, perennial ryegrass and fescue.

Finally, replicated field trials in commercial orchards were established in 2001/02 on apples (at Mooroopna North and Silvan) and on pears (Templestowe) and in 2002/03 on apples (Harcourt and Red Hill). Insect numbers were monitored during the season using yellow sticky traps, while fruit yield and quality were assessed at the end of the trials.

Overall, the buckwheat and chicory/yarrow treatments were marginally the best performers based on the yield and damage data.

The most common form of fruit damage was russeting. This may have been induced by the relatively tall canopies of the cover crops, which maintained higher relative humidity in those plots.

Problems were encountered in establishing effective ground cover crops on orchard sites grown using biodynamic principles, where many plots became overrun with weeds. In addition, the drought in 2002/03 meant that two sites were abandoned because water for the plots was not available.

Much more field testing is required before the value of cover crops for pest management is established. It is vital that cover crops can be easily grown under the existing agronomic practices in the orchard. We also need to learn much more about the movement patterns of beneficial and pest insects between cover crops and orchard trees.

Technical Summary

Effective IPM programs for pome fruit crops require sufficient numbers of beneficial insects such as coccinellids, lacewings, syrphids and wasp parasitoids to be present in the orchard at the appropriate time. Even when selective insecticides are used that are relatively harmless to these natural enemies, commercial orchards can be inhospitable places for beneficials because of a lack of food (nectar, pollen or alternative prey) and shelter. Provision of flowering plants as refugia for beneficials can allow for more effective colonisation and performance of these natural enemies. This project (the basis of a postgraduate study by Nicole Bone, La Trobe University), was in three stages:

(a) Desktop study to review progress in habitat manipulation and conservation biological control. From the extensive literature review, 22 different plant species were selected for testing in the glasshouse for susceptibility to LBAM, in terms of attractiveness to (i) oviposition and (ii) survival of larvae.

(b) Testing of potential cover crops in the glasshouse to determine their susceptibility to the main pests, focussing on light brown apple moth (LBAM).

(c) Field evaluation of a range of cover crops in commercial orchards in northern and southern Victoria.

Replicated field trials in commercial orchards were established in 2001/2002 at in the Goulbourn Valley on apples (Mooroopna North) and the Yarra Valley on apples (Silvan) and pears (Templestowe). In 2002/2003, trials were established on apples (Harcourt and Red Hill) and pears (Merrigum). Cover crops tested were buckwheat, (Polygonaceae); white mustard, (Brassicaceae); chicory, yarrow, (Asteraceae); fennel, Queen Anne's lace, (Apiaceae); *Phacelia*, borage, (Hydrophyllaceae); perennial ryegrass, fescue, (Poaceae); fenugreek (Fabaceae).

Overall, the buckwheat and the chicory/yarrow treatments were marginally the best performers based on the yield and damage data. At Mooroopna North, the apple weight and diameter was greatest for the chicory/ yarrow treatment while the Queen Anne's Lace /fennel treatment resulted in the smallest and lightest fruit. At Silvan the buckwheat, ryegrass and fescue and the chicory and yarrow treatments produced the largest and heaviest fruit while the Queen Anne's Lace/fennel and also the mustard treatments resulted in the lightest apples. There were no significant differences in yield between treatments at Templestowe and Red Hill (the only other trial sites which could be sustained to harvest).

Significant differences between treatments in terms of fruit damage was only observed for russet damage at the Mooroopna North site ($p=0.006$) where the mustard and the ryegrass/ fescue treatments resulted in the greatest and least amount of russeting respectively.

Insect numbers were monitored during the season using yellow sticky traps while fruit yield and quality were assessed at the end of the trials. Brown lacewing (*Micromus tasmaniae*) populations were not significantly different over the six treatments while green lacewing (*Mallada signata*) numbers were too low over all plots to be analysed. There were no significant differences in thrips numbers at Red Hill between the 3 treatments tested.

There were major logistical difficulties encountered during these field trials. We had great trouble establishing effective ground cover plots on the sites being grown under biodynamic principles. Without the use of herbicides, many of the plots became overrun with weeds and establishment of the test cover crops was unsatisfactory. Because of the severe drought in 2002/2003, several of the sites had to be curtailed because the growers were unable to water the cover crops beyond December.

With hindsight, the project was too ambitious in terms of the resource requirements for running six fully replicated field trials, with replicates of a sufficient size to minimize inter-plot interactions. Consequently, the difficulties experienced in establishing satisfactory cover crop plots compromised our ability to assess adequately the influence of these cover crops on arthropod populations.

Further research is needed before unequivocal recommendations can be made to industry about the deployment of cover crops for promoting natural enemy abundance. Firstly, the most important natural enemies need to be identified in order for the appropriate floral characteristics be elucidated for selecting the most useful cover crops. This is likely to require the development and use of molecular markers to provide a much deeper understanding of the roles of potential predators. Secondly, it is vital to have a better knowledge of movement patterns of arthropods (both pest and natural enemies) between the orchard trees and the cover crops. It is important to know whether a particular cover crop is acting as a source or sink of natural enemies. Thirdly, the agronomic costs and benefits of the cover crops on the orchard trees must be fully assessed, particularly with the increased use of trickle irrigation.

Introduction

Increasing focus is being paid worldwide on the potential role of cover crops in orchards. As integrated fruit production management strategies replace broad-spectrum chemical use for pest, disease and weed control, there is a growing need for research on identifying potential cover crop species and their benefits in orchard fruit production.

Orchard pest management has progressed in recent years to utilize more fully the principles of integrated pest management, where decisions to apply control methods are based on careful monitoring of the primary insect and mite pests experienced in the orchard. Synthetic pesticides are being applied more on a needs basis rather than regular blanket sprays throughout the growing season and the use of softer chemicals, which are specific to the pest concerned, is increasing. These strategies should ensure that sufficient numbers of beneficial insects and mites such as lacewings, coccinellids, phytoseiids, syrphids and wasp parasitoids are present in the orchard at the appropriate time.

Even when selective insecticides are used that are relatively harmless to these natural enemies, commercial orchards can be inhospitable places for beneficial insects because of a lack of food (nectar, pollen or alternative prey) and shelter. Providing flowering plants as havens (refugia) for beneficial insects can allow for more effective colonization and performance of these natural enemies. However, a targeted approach to selection of appropriate insectary plants is needed to ensure that the orchard system is benefited (e.g. that additional pests or diseases are not promoted).

Cover crops are significant in providing alternative food and host sources, protection from climatic conditions and overwintering sites for beneficial insects. Current orchard practice encourages the use of cover crops to increase soil nutrients and organic matter, decrease ground water loss and for improving soil structure. There is also evidence to suggest that cover crops can decrease the incidence of soil-borne diseases in fruit trees. However, the role of cover crops and of other vegetation in supporting populations of beneficial insects is not clear.

An example of successful habitat management is the use of inter-row plantings and windbreaks in the Australian citrus industry. Plantings of Rhodes grass between rows encourage high populations of predatory mites, and *Eucalyptus* trees planted as windbreaks also increase predatory mite numbers (Smith and Papacek, 1991).

In this project, candidate plant species are to be tested for their potential to provide food and host sources, and/or protection for beneficial insects and mites. Plants would be checked to ensure they do not favour multiplication of lepidopteran pests, in particular lightbrown apple moth, *Epiphyas postvittana*.

Much international research has focused on the benefits of cover crops for aspects other than the propagation of beneficial arthropods. Soil-borne diseases and pest nematodes have received considerable attention: The effect of canola and various grasses on severity of Phytophthora crown and root rot of apple trees in Canada was studied by Utkhede and Hogue (1999), while Pruyne *et al.* (1994) evaluated cover crops for suppression of soil nematodes which create replant problems in New York. Merwin (1997) discussed the use of cover crops as alternatives to soil fumigation and found that perennial ryegrass and alpine bluegrass reduced levels of root-lesion nematodes.

In Australia, erosion control in newly established orchards using cover crops has been studied (Wilson and Firth, 1992). Firth and Wilson (1995) then assessed 13 cultivars over 7 years for suitability for erosion control by measuring establishment, growth height and percentage ground cover.

Research suggests that cover crops can adversely affect orchard tree growth and yield. Ground covers of brome, hard fescue and rattail fescue have been found to severely affect the vigour of young peach trees (Meyer *et al.,* 1992), and ground cover management strategies can reduce growth, yield and nutrient uptake of apple trees (Merwin and Stiles, 1992).

Cover crops clearly have potential to affect both the beneficial and pest arthropod faunas of orchards. Altieri and Schmidt (1986) tested the effect of cover crops on insect pests and their natural enemies in Californian orchards. Orchards with cover crops were found to have lower levels of pest infestation and more predators than did orchards with cleared ground. Meyer et al (1992) found that some cover crops harboured unacceptable levels of pest arthropods, while others increased populations of beneficial insects. *M. schreberi*, a perennial grass, was the most promising ground cover species. Smith *et al.* (1994) evaluated potential ground covers to increase beneficial arthropod populations in pecan orchards. Two annual legumes, planted together produced the greatest increase in beneficial insects (primarily ladybird beetles).

Current research in Australia (Firth *et al.*, 2003) is investigating the effect of ground covers for macadamia orchards. Evaluation of the best selections and screening of new species is underway. This research may be useful in guiding selection of potential cover crop species for pome fruit orchards. In New Zealand, Harrington and Popay (1995) screened ground covers in an apple orchard and found that white clover, hard fescue and cotula were the most promising species. Harrington and Rahman (1998) have since tested the tolerance of ground cover species to herbicides.

This project is directed at understanding roles of the orchard environment in supporting indigenous populations of natural enemies. If the habitat requirements of natural enemies are fully recognized, then practices can be developed to maximize their occurrence in the orchard. Specifically, the project investigated methods of improving the habitat of pome fruit orchards by the application of cover crops. Experience shows us that although natural populations of beneficial insects are present in orchards, their abundance is seasonally and geographically variable. This variability can account for failures in biocontrol. The role of cover crops in providing additional sources of food, shelter and overwintering sites, and their subsequent effect on population levels, will be investigated.

The project (which was the basis for a postgraduate study by Nicole Bone, La Trobe University), was in three stages:

(a) Desktop study to review the rapidly expanding world scientific literature in this area of habitat manipulation and conservation biological control. The aim was to streamline the selection of potential plants for testing as cover crops which would promote the survival of beneficial insects. These types of plants are known as insectary plants.

(b) Testing of potential cover crops in the glasshouse to determine their susceptibility to the main pests. We focussed on light brown apple moth (LBAM), the native leaf roller which has a very wide host range. It was important not to plant crops which would increase numbers of LBAM.

(c) Field evaluation of a range of cover crops in commercial orchards in northern and southern Victoria.

The study was designed to provide pome fruit growers with information on which plants produce optimum survival conditions for beneficial orchard insects and mites.

Desktop Study

Orchard habitat management to enhance integrated pest management systems

Background

The escalating prevalence of pesticide resistance, increasing awareness of possible detrimental health effects and resulting deregistration of broad-spectrum pesticides has forced a shift towards alternative and sustainable methods of pest control in Australian pome fruit orchard agroecosystems. Biological control has become an important aspect of orchard pest control yet it still remains, for the most part, an unreliable and unpredictable method of pest management (MacHardy, 2000). Frequently, key species of beneficial arthropods are below the population density needed to keep pest arthropods populations in check. In order for beneficial arthropods to reach optimal population densities when needed, they must have access to all of the basic resources such as food and shelter. Landis *et al.,* (2000) defines habitat management as

> "…a subset of conservation biological control methods that alter habitats to improve the availability of the resources required by natural enemies for optimal performance. Habitat management may occur at the within-crop, within-farm or landscape levels. Underlying these practices is the understanding that the agricultural landscapes often do not provide resources for natural enemies at the optimum time or place."

A sketchy framework of ecological theory exists for habitat management and there has now been considerable research published in the last decade (Cortesero *et al.,* 1999; Gurr *et al.,* 1998, 2004; Landis *et al.*, 2000; Pickett and Bugg, 1998).

In this review, the role of habitat management in pest management systems is explained and each of the systems defined. A range of resources is important for beneficial arthropod populations and these are identified. Habitat management involves the cultivation of flora that provide these resources and it is discussed how these may be selected to specifically enhance survival of beneficial and not pest arthropods. The methods by which the candidate plant species may be selected are explored.

Ecological principles of habitat management

The ecological theory of habitat management is still evolving and may allow researchers to fine tune approaches to sustainable biological control in a more structured manner rather than the 'hit and miss' attempts that have dominated past attempts. Examples from a range of agroecosystems have been used to best demonstrate the concepts and these apply equally well to the orchard agroecosystem as to those in which they have been demonstrated. The key components of habitat management centre on diversity and disturbance.

Root (1973) proposed that the reason for the often high numbers of herbivores in simple agroecosystems were due to: 1) the 'natural enemies hypothesis' and 2) the resource concentration hypothesis. The natural enemy hypothesis states that diversity encourages predators and parasites and/or their effectiveness. The resource concentration hypothesis involves specialist herbivores being favoured by simple systems (monocultures).

Andow (1991) explored the interaction of plant diversity and arthropods. He explored the two main approaches to understanding polycultures. The first is that each polyculture is unique and that each element of a particular polyculture needs to be understood. The second is that ecological theory once fully developed will allow us to predict the response of arthropods to polycultures. Andow (1991) reviewed the results of 209 studies of 287 herbivorous arthropod species. He found that 51.9% of the species were at a lower density in polycultures compared to 15.3% that increased in density while 20.2% demonstrated variability in their response.

Natural enemies exhibited a similar response with 52.7% of 80 species having higher densities in polycultures compared to 9.3% having lower densities. These findings are biased by the fact that many unsuccessful manipulations may not have been reported.

The concept that increased diversity would benefit the increase of beneficial arthropods has been pushed by several authors. However, it has become apparent that a general increase in diversity can also favour an increase in polyphagous pests. This has led to the view that selective vegetational diversity rather than general diversity was the key to successful biological control. The issue has become one of which plants should be introduced or maintained within an agroecosystem (Smith and McSorley, 2000).

Leius (1967) assessed 15 Canadian orchards for the flowering understorey diversity. He believed that orchards with a rich diversity had greater parasitism of tent caterpillar larvae and codling moth larvae. He also found greater parasitism of tent caterpillar eggs but when Schoenig *et al.*, (1998) reanalysed these data, they were found to be not significant.

Orchards, as with any other type of agroecosystem, are subject to disturbance in many forms and on varying timescales. Natural disturbances such as drought, flood and fire may take place on a seasonal basis while disturbance such as pesticide sprays may happen very frequently. Within annual field crop ecosystems, harvest each year causes a major disturbance while perennial systems as in the case of pome fruit orchards are generally less frequently undergo disturbance of such intensity (Landis and Marino, 1999; Landis and Menalled, 1998).

After each disturbance, recolonisation of the area will occur. Beneficial arthropods, the third trophic level, will be comparatively slow to recolonise as the two lower levels must first be in place. In perennial systems such as the pome fruit orchard, disturbance may be far less intense than in annual systems yet still quite detrimental to the beneficial contingency. Some disturbances may be avoided, such as irrigating orchards in areas of marginal rainfall. Many disturbances cannot be avoided so must be managed by minimising their impacts. An example of this is the provision of refuge habitats in and near areas subjected to pesticide sprays. These refuge habitats may be natural such as strips of unmanaged grasses or be artificial. Non-crop vegetation in orchards is an important refuge for beneficials when the crop trees are sprayed, and can serve as reservoirs of beneficial arthropods for recolonisation of sprayed areas.

Pest control options

Conventional control relies heavily upon pesticide applications. Chemical control of arthropod pests can be very successful, however, a number of problems have been encountered.

The health of orchard workers and possibly consumers was compromised by organophosphate use and led to the subsequent deregistration of a number of key chemicals.

Arthropods normally considered secondary pests in some cases reached economic thresholds. Pesticide resistance has become an issue as a consequence of conventional control, such as two-spotted mite, *Tetranychus urticae*. The highly polyphagous and resilient nature of *T. urticae* allows it to infest a wide range of fruit and ornamental crops in many countries. Conventional control also knocks out natural enemies of secondary pests that previously kept these species in check, and removal of major pests broadens the niche space available to secondary pests.

Integrated pest management (IPM) entails both pesticide use and cultural control. IPM methods vary widely from those that rely more heavily upon chemicals to those that use chemicals infrequently. IPM differs from conventional control in that pesticide application is more targeted and 'blanket' use is avoided. Prokopy *et al.* (1996) outlined a multi-level IPM system and compared arthropod pest and natural enemy numbers in first-level (chemical control) compared to second-level commercial IPM orchards in Massachusetts.

Biological control harnesses the third trophic level and is an important component of IPM. In this review, we will follow the definitions of Eilenberg *et al.* (2001). Their definitions are:

Classical biological control
'The intentional introduction of an exotic, usually co-evolved, biological control agent for permanent establishment and long-term pest control'

Inoculation biological control
'The intentional release of a living organism as a biological control agent with the expectation that it will multiply and control the pest for an extended period, but not permanently'

Inundation biological control
'The use of living organisms to control pests when control is achieved exclusively by the released organisms themselves'

Conservation biological control
'Modification of the environment or existing practices to protect and enhance specific natural enemies or other organisms to reduce the effect of pests'

Habitat management and pest control

Habitat management involves making the crop environment as conducive to beneficial arthropod efficacy as possible. Basic requirements that need to be met for survival of beneficial arthropods include:

1) plant-derived sustenance for species that are either phytophagous, particularly at the adult stage, or are omnivorous at any stage;

2) alternative hosts or prey to allow populations to at least subsist while target pests are at low densities,

3) shelter for protection from the elements and also for overwintering.

While the basic requirements for members of the third trophic level are few, a vast array of ways exists in which the pome fruit orchard environment may be manipulated to favour them over other trophic levels. The basic requirements for maintaining and manipulating beneficial arthropods in the orchard situation are discussed.

(i) Parasitoids

Parasitoids are the most significant group of natural enemies used in biological control of orchard pests (Viggiani, 2000). The majority of parasitoids important in IPM are native species and not imported exotic species.

Parasitoids exhibit a range of life-histories and therefore collectively attack a broad range of hosts and life-stages. They may be endo- or ectoparasitic and either solitary or gregarious. Frequently, the ecology of the adults is overlooked. The majority of orchard parasitoids are free-living as adults (protelean) although some feed on host body fluids or honeydew. A great number of these species will also, or exclusively, feed upon plant carbohydrates and proteins such as nectar and pollen.

Parasitism rates can be high in many agroecosystems, although is hindered by the occurrence of inter- and intraspecific competition. Superparasitism of a host occurs within a species that have not evolved a method of avoiding parasitised hosts by using chemical or visual cues. Multiparasitism by different species can produce viable parasitoid offspring but as with superparasitism often will result in the death of all larvae.

While parasitoid diversity enables the suppression of many pest species, it also allows for beneficial species to be attacked themselves. Parasitism of predatory species is not uncommon and beneficial parasitoid species often become hosts themselves (hyperparasitism). A number of adaptations occur in the larval and pupal stages to enable endoparasitism and these mostly involve obtaining an adequate air supply and avoiding polluting the host with their own waste.

The parasitoid lifecycle must be in synchrony as possible with host voltinism and involves diapause and sometimes alternative hosts. The adult female must be able to locate a suitable host and any supplemental food sources with minimal energetic investment. This is mediated using environmental cues/signals. A problem with parasitoids is that their populations are very much reliant upon the host population/s. This is particularly the case at the start of the season after overwintering when parasitoid numbers can be extremely low.

Hymenopteran parasitoids are the most frequently encountered parasitoid /natural enemy group within the fruit orchard (Viggiani, 2000). The group is diverse and many species remain undescribed partly due to the small size of some species, particularly those that use insect eggs as their host. The group is noted for its highly specialised morphology, physiology and behaviour to enable their parasitoid lifestyle.

There are several major groups of parasitoids likely to be beneficial in orchards. The chalcidoids (superfamily Chalcidoidea) include the Aphelinidae, Encyrtidae, Eulophidae, Mymaridae, and Trichogrammatidae. *Aphelinus mali* (an aphelinid) parasitises the woolly aphid, *Eriosoma lanigerum.* The braconids include the Aphidiinae that parasitise aphids, while the ichneumonids include parasitoids of moths and beetles. There are also a few families of Diptera that consist of some parasitic species, and in particular it is the large tachinid family that has been the focal point of dipteran parasitoid studies. Tachinids exhibit less individual host specificity than hymenopteran parasitoids and the family collectively utilises a wide host range.

(ii) Predators

Predatory species demonstrate far greater diversity than parasitoid species both in the taxa that they belong to and the taxa they prey upon. In the Coleoptera, a number of families within this order contain predators. The two most important families are the Coccinellidae (Maredia *et al.*, 1992), and the Carabidae (Miñarro and Dapena, 2003). In the Neuroptera, there are a large proportion of predators. The most documented and probably the most important groups are the Chrysopidae (green lacewings) and Hemerobiidae (brown lacewings). Lacewing larvae primarily consume aphids, scale insects, mealybugs, whiteflies and mites. Many hymenopteran species, including vespid and sphecoid wasps, are predatory. Many ants attack economically important pests but some species are pests themselves. The Diptera contains some parasitic and predaceous groups. The Asilidae, robber flies, are quite remarkable as some species catch their prey ‘off-the wing’. The Syrphidae, hover flies, are also important generalist predators (White *et al.*, 1995). The Phytoseiidae are a very important family of mite predators in orchards.

Resources important in habitat management

Numerous studies have demonstrated the importance of the availability of nectar to adults of beneficial species. Adults of numerous parasitoid species exhibit increased longevity when provided with nectar (e.g. Dyer and Landis, 1996; Idris and Grafius, 1995, 1996; Takasu and Lewis, 1993). They also spend a greater proportion of time searching for hosts (patch retention time) and, in some species, nectar is necessary for egg maturation. A comprehensive survey in the U.K. (Jervis *et al.,* 1993) demonstrated the extent of exploitation of floral nectar by hymenopteran parasitoid taxa. They surveyed the inflorescences of 32 plant species for feeding by adult hymenopteran parasitoids. More than a thousand hymenopteran species were found to be feeding upon the inflorescences.

Laboratory trials have demonstrated increased longevity in parasitoids such as *Trichogramma carverae* Oatman and Pinto, *Trichogramma* nr *brassicae* Bezdenko (Hymenoptera: Trichogrammatidae) (Gurr and Nicol, 2000), and *Cotesia rubecula* (Wäckers and Swaans, 1993). Longevity of males and females of *Cotesia rubecula* increased by 9-14 fold when they were fed with floral nectar or honeydew (Wäckers, 2001; Wäckers and Swaans, 1993).

Extrafloral nectar is present on some plants across several families. While nectaries in flowers are often obscured by surrounding structures such as the corolla etc, extrafloral nectaries are quite usually quite open in structure. This unique structure allows them to be exploited by insects with a range of mouthpart morphologies that may be restrictive in the types of flowers upon which they are able to feed. The impact of extrafloral nectaries has been well demonstrated in cotton (Adjei-Maafo and Wilson, 1983a). A nectary-less isoline of cotton was developed with the initial intent of minimising adult lepidopteran feeding. However, not only did it reduce the moth population, but it had an even greater impact upon the entomophagous coccinellid population. Approximately half of the pest groups showed almost no reduction in density while the other half showed a reduction of 24–42%. However, all beneficial groups were reduced in abundance by 38–69% in a 4-yr study (Adjei-Maafo and Wilson, 1983a). Despite a 40% reduction in pest damage (Adjei-Maafo and Wilson, 1983b) the nectary-lacking line is rarely grown due to its negative impact on beneficial insect numbers.

Wasps and ants have been associated with plants with extrafloral nectaries. In some cases the hymenopteran-plant association is actually a symbiotic relationship where the plant produces a nectar reward for the hymenopterans in exchange for the protection that the insects afford. One such example is *Ipomoea pandurata* (Beckmann and Stucky, 1981).

While extrafloral nectar may not be of sufficient nutritional value to allow arthropod development to proceed, it can be a very important carbohydrate source that increases longevity when prey are absent and allows the arthropod to continue searching for prey. Extrafloral nectar increased the longevity of first-instar larvae of the omnivorous green lacewing, *Chrysoperla plorabunda* and allowed them to keep searching for prey (Limburg and Rosenheim, 2001). Pemberton and Vanderberg (1993) that 41 species of coccinellid beetles from a range of families have been observed feeding upon extrafloral nectar of 32 plant families in several countries. It is thought that extrafloral nectar increases coccinellid longevity when prey is unavailable. Parasitism has been reported to be higher on plants that bear extrafloral nectaries. Parasitism of gypsy moth, *Lymantria dispar*, eggs, larvae and pupae was greater in the extrafloral nectary bearing forest plants in a South Korean study (Pemberton and Lee, 1996).

Gurr *et al.* (1998) suggested there may be little use for honeydew in habitat management programs as pests such as aphids cannot be allowed to damage the crop. However, when the honeydew-producing insect such as a non-pest aphid is located on a non-crop plant, then honeydew may be useful particularly when nectar sources are unavailable (England and Evans, 1997).

Pollen can also be an important food source for predatory mites (Addison *et al.,* 2000; Ouyang *et al*., 1992). While the larvae of syrphids are predatory, adults consume pollen as an amino acid/protein source and have been shown to increase in number when certain plants with a plentiful and readily accessible supply of pollen are grown near the crop when nectar is also available. Some predatory mite species are able to subsist or develop normally upon pollen in the absence of prey. *Euseius tularensis* a predatory mite found in citrus trees was shown to reproduce using this resource (Grafton-Cardwell *et al.,* 1999). Pollen must be consumed for maturation of the reproductive system of syrphids (Cowgill *et al.,* 1993).

Alternative prey can be particularly important at the beginning of the season for entomophagous insects such as lacewings and coccinellids. The presence of alternative prey can enable these insects to build up their populations before the target pest reaches high numbers and before specialist predators and specialist parasitoids have located the target species. One of the best examples of the need for alternative hosts are the *Anagrus* parasitoids that parasitise grape leafhoppers (*Erythoneura elegantula*; Homoptera: Cicadellidae) in Californian vineyards.

Apart from food, shelter can be important on large to small scales such as the landscape, orchard, orchard block, tree and the microscopic scales. On a landscape scale vegetation outside of the orchard can be important by providing a refuge habitat. Corbett and Rosenheim (1996) studied the affect of French prune tree refuges on *Anagrus*, parasitoids of the grape leafhopper, an important vineyard pest in California. *Anagrus* is unable to overwinter within the orchard and through rubidium-labelling *Anagrus* overwintering in French prune refuges, they found that 1% to 34% of the *Anagrus* in the vineyards originated from the refuges. A later study (Murphy *et al.,* 1998) revealed that the refuges significantly increased rates of parasitism in the first but not the second or third generations of the leafhopper indicating that the refuges are important for early season parasitism. A higher concentration of *A. epos* was found on the leeward side of the trees, indicating a windbreak effect (Murphy *et al.,* 1996). *Phytoseius fotheringhamiae*, a predator of eriophyoid mites, some stages of tydeid mites and young *Bryobia* mites overwinter on shelter structures on apple trees but a portion of the mites overwinter in the cover crop (Schicha, 1975).

Windbreaks can provide shelter for a large portion of an orchard and can create more favourable conditions within an orchard block which may allow a greater level of commuting by beneficial arthropods, in particular those that traverse large distances such as lacewings. On a smaller scale, plants can provide shelter for beneficials when inclement conditions prevail (Gange *et al.,* 1998).

The plant architecture can greatly influence local microclimate, increasing humidity during hot days when some insects are particularly prone to desiccation. On a microscopic scale, small arthropods such as predatory mites are able to utilise small structures for shelter such as trichomes, mid-veins, leaf domatia and so on. For instance, *Metaseiulus occidentalis* consumed significantly more two-spotted mite (*Tetranchychus urticae*) eggs on *Viburnum tinus* (Caprifoliaceae) leaves with domatia compared to those with the domatia excised, while egg laying rates of the predatory mite were also lower on leaves without the domatia (Grostal and O'Dowd, 1994).

Plant characters important in screening of plants for habitat manipulation

With the need for 'selective vegetational diversity' as opposed to a general increase in diversity there has been a move towards criteria-based selection of candidate plant species. When choosing a candidate plant it is important that they are 'selective food plants' in that they will provide a nectar or pollen reward for the beneficial arthropod species but not to pest species. An approach to selecting candidate plant species is to look at the pollinator isolating mechanisms that the plants possess. Candidate plant resistance to herbivore pests is also important and may be tested using basic screening procedures. Alternative prey and host arthropods may also be valuable in beneficial population stability and may be supported by certain host plants. Also, the agronomic characteristics of the plant candidates must be considered.

Floral architecture can determine the type of insect visitor (e.g. Patt *et al.,* 1997). Flower structure can range from exposed nectaries such as those found in the umbel of a number of Apiaceae including fennel, exposed nectaries on a cyathium, partially hidden nectaries on an umbel, partially hidden nectaries in a cup- or bowl-shaped flowers or hidden nectaries in a capitulum (Patt *et al*., 1997). Many plants that have extrafloral nectaries are not compatible with mouthparts of some beneficial insects (Wäckers *et al.,* 1996). This selective mechanism can be used as positive attribute where a plant's floral structure can prevent a target or group of target pests from utilising the nectar while allowing the beneficial insects to use them. Careful morphometric combined with longevity and fecundity studies can allow researchers to elucidate if a candidate plant is suitable.

Nectar is comprised of a range of constituents such as a variety of sugars, amino acids and some lipids and the types and ratios of these vary considerably between plant taxa. Nectar composition can influence the attractiveness of nectar to certain arthropod pollinators and possibly the nutritional value. While nectar contains a range of sugars, the most common sugars are sucrose and the hexose sugars, glucose and fructose (Baker and Baker, 1983). While composition is largely genetically determined and indeed plant families often show trends in composition, a great deal of variation can be demonstrated even within variety due to a range of environmental factors (Stapel *et al.*, 1997)) Variation also occurs between types of nectaries. Nectars are categorised as either high ratio of sucrose to hexose (>0.5) or a low ratio (<0.5) (Baker and Baker, 1990). Insects amongst a variety of pollinators have been linked to certain sugar ratios (see Baker and Baker, 1990). Sucrose-dominated nectars were found to be attractive to lepidoptera, long-tongued bees and wasps while hexose-rich are pollinated by short-tongued bees and flies (Baker and Baker, 1990). Some plant families tend to produce nectars that are sucrose-rich such as Lamiaceae and Ranunculaceae and others produce hexose-rich sugars such as Brassicaceae and Asteraceae (Baker and Baker, 1983). However, some families such as Scrophulariaceae are inconsistent in the nectar:sugar ratio (Baker and Baker, 1983).

While very little attention has been paid to this subject, there is some evidence that some sugar types, only detectable in nectars as trace sugars, may be toxic to some insect species. There is also some evidence to suggest different sugars may have better nutritional value for different insect species.

These factors combine to make some flowers more suitable for some species. For instance, the braconids, *Pholetesor ornigis,* shows increased fecundity when confined with flowers of creeping “Charlie” (*Glechoma hederacea*), dandelion (*Taraxacum officinale*), and apple (*Malus domesticus*) but not with blossoms of chickweed (*Stellaria media*) or Shepherd’s purse (*Capsella bursa-pastoris*) (Hagley and Barber, 1992).

Nectar secretion patterns can vary from a diurnal to a seasonal basis and can impact greatly upon arthropod visitation to nectaries. Many plants exhibit patterns of nectar secretion on a 24-hr timescale. Some plants secrete nectar in the morning and drop off secretion of nectar later in the day. Heat increases the viscosity of some nectars, and may make it difficult for moths to feed but not short tongued insects. Certain species of insects forage at particular times of the day. Bees for example forage primarily during the morning. Noctuid moths forage mostly on dusk. Perhaps it might be possible to choose plants that only secrete nectar in synchrony with beneficial arthropods but not pests.

The importance of a nectar supply early in the season has been suggested by several researchers to be important for a steady population increase after overwintering. An increased length of time spent flowering will also increase the usefulness of a plant in habitat manipulation.

Floral colour can differentially attract arthropod pollinators. Syrphids are commonly attracted to bright yellow. Blue sticky traps are used to selectively attract thrips (Vernon and Gillespie, 1990) Flower colour may play a small role in the choice of selective food plants. Selecting plants for their floral colour is difficult due to the difference between the human eye colours and insect eye colours.

Cover crop and wind break plants can harbour a range of arthropods that may be consumed by natural enemies of pests of the fruit trees. When prey within the fruit trees is scarce the natural enemies may be able to at least subsist on a diet of the alternative prey. However, when prey within the non-crop vegetation is preferred to the prey within the trees, migration into the trees may be limited. It is vital to have a better knowledge of movement patterns of arthropods (both pest and natural enemies) between the orchard trees and the cover crops. It is important to establish whether a particular cover crop is acting as a source or sink of natural enemies. (Coll and Bottrell, 1996; Dorn *et al.*, 1999).

Agronomic characteristics of cover crop plants

While plants may enhance beneficial populations they may also harbour polyphagous pests and non-host specific diseases. Although plants may not directly harbour diseases of fruit trees, they may create a more favourable environment for the growth and dispersal of these diseases. For example, tall cover crops create a more humid environment within the tree canopy that favours growth of diseases such as powdery mildew.

Much international research has focused on the benefits of cover crops for aspects other than the propagation of beneficial arthropods. Soil-borne diseases and pest nematodes have received considerable attention: The effect of canola and various grasses on severity of Phytophthora crown and root rot of apple trees in Canada was studied by Utkhede and Hogue (1999), while Pruyne *et al.* (1994) evaluated cover crops for suppression of soil nematodes which create replant problems in New York. Merwin (1997) discussed the use of cover crops as alternatives to soil fumigation and found that perennial ryegrass and alpine bluegrass reduced levels of root-lesion nematodes.

Research suggests that cover crops can adversely affect orchard tree growth and yield. Ground covers of brome, hard fescue and rattail fescue have been found to severely affect the vigour of young peach trees (Meyer *et al.,* 1992), and ground cover management strategies can reduce growth, yield and nutrient uptake of apple trees (Merwin and Stiles, 1992).

Candidate plants must be well suited to environmental stresses encountered within the orchard. Environmental stresses such as drought, frost and soils of variable fertility or structure are common and can be one of the greatest criteria in selecting candidate plants. Disease resistance is important for candidate plant vigour and minimal maintenance such as mowing or pruning are important. While these plants must be hardy they should not compete overly with the fruit trees for water and nutrients. Candidate plants should be assessed for their potential to become weeds. Care should be taken in assessing toxicity risks of the plants to humans and any local livestock e.g. buckwheat causes photosensitivity in horses.

In Australia, erosion control in newly established orchards using cover crops has been studied (Wilson and Firth, 1992). Thirteen cultivars were assessed for suitability for erosion control by measuring establishment, growth height and percentage ground cover (Firth and Wilson, 1995).

Competition is a substantial problem of cover crops. A number of studies (Firth and Wilson, 1995; Wilson and Firth, 1992) have shown a decrease of tree growth when grown with a cover crop compared to bare ground. For instance, Firth *et al.* (2003) demonstrated decreased growth but not consistently lower yield when macadamias were grown with *Arachis pintoi* cv. Amarillo.

While cover crops may compete for nutrients with the fruit trees, some cover crops are useful as nutrient catch crops. Legumes are commonly used as a nitrogen catch crop. Many species improve soil structure especially compared to clean cultivated crops where compaction is a problem. Increased organic matter in the soil resulting in turn promotes increased biological activity within soils and subsequently increased water infiltration and water holding capacity. Green manure cover crops allow organic matter and nutrients to be put back into the soil and in some cases may double as insectary crops.

Plant architecture must suit the specific needs of the orchardist. In most cases cover crops need to be tolerant to machinery and other traffic. Generally low-growing cover crops are best as they are often require the least amount and are most tolerant to mowing

Weed suppression is also important, particularly that of broad-leaved weeds that may harbour polyphagous pests etc. The root system of buckwheat (*Fagopyrum*) produces toxic allelochemicals that suppress weed growth even after senescence. Other plants outcompete with weeds by germinating and growing quickly.

In New Zealand, Harrington and Popay (1995) screened ground covers in an apple orchard and found that white clover, hard fescue and cotula were the most promising species. Harrington and Rahman (1998) have since tested the tolerance of ground cover species to herbicides. In selecting suitable species, a screening process needs to be undertaken. For instance, Burnip and Suckling (1997) screened legumes for their resistance to *Epiphyas postvittana* for use in pome fruit orchards. Potted plants were placed in cages in a glasshouse and outside. Both oviposition and larval development studies were undertaken in this screening process.

Methods of selection of candidate plants

Microcosm studies include testing of plants in Petri dishes to potted plants in cages. They provide an efficient method of testing candidate plants for resistance to pests and diseases and for their ability to support beneficial arthropods. Many limitations exist with these methods so they are commonly used as a method of selecting a set of candidate plants to be field tested. One of the most obvious limitations is that not all the relevant pests and natural enemies can be laboratory tested. Candidate plant-arthropod interactions are very complex and are difficult to predict.

Field trials can be implemented on several scales. Potted plants have been placed in cages. Other trials have involved small test plots in an effort to identify the insects they support and if the cover crops are vigorous (e.g. Bugg *et al*., 1990a, b; Bugg and Ellis, 1990). An inherent problem with testing cover crops outside of the orchard environment is that the many of the arthropods found in association with the crop trees will not be present. Other trials have involved small plots around target trees (Stephens *et al.*, 1998), rows or plots of cover crops around vines or trees. Some trials have involved multiple orchards and while, these are large-scale, some have not been properly replicated (e.g. Altieri and Schmidt, 1985).

Implementing habitat management in orchards

The role of hedgerows in habitat management has been assessed by several researchers but far less extensively than cover crops. A French study assessed fauna in a hedgerow orchard and found that the samples from ivy contained many of the same beneficial species as the pear trees and, as they are evergreen, they provide shelter. Ash trees contained ‘host specific psyllids and gall midges’ which are alternative prey to beneficial species (Rieux *et al.*, 1999). Lewis (1969) found greater diversity in aerial samples taken above hedges than compared to those taken above the adjacent bean crop and pasture. He concluded that most of the hedgerows would not have much of an effect in large fields but may be important in small fields. To date no studies have been conducted where hedgerows or border trees have been planted in a replicated study. This is possibly due to the number of years after planting it would take to realise the effects of the border plantings. From an agronomic perspective border plantings might be much easier to incorporate into the orchard agroecosystem than cover crops and would be far less labour intensive. For these reasons they may have a greater rate of grower adoption of this method if proved to be successful. However, as cover crops are in much closer proximity to the crop trees, they have far greater potential for the manipulation of the relevant arthropod complex.

Cover crops have been used extensively in orchard systems for enhancement of a range of beneficial arthropod populations (Alston, 1994; Bugg and Waddington, 1994; Fye, 1983; Wyss, 1996; Yu-Hua *et al.*, 1997). Simply allowing a range of volunteer plants to grow in the orchard understorey has had mixed success due to the pests and diseases that some plants may harbour (Utkhede and Hogue, 1999). The use of sown cover crops is allowing for less error to occur. While tritrophic interactions are complex and highly variable within and between orchards, we are able to predict which cover crops are likely to be the best performers for a specific orchard by identifying existing arthropod populations and using selection criteria.

Very few studies have assessed the impact of both shelterbelts and groundcovers. Smith and Papacek (1991) tested the effects of pesticides, groundcovers, shelterbelts and augmentative release on *Amblyseius victoriensis* (Acarina: Phytoseiidae) and its prey *Tegolophus australis* and *Phyllocoptruta oleivora*. They found that windbreaks of *Eucalyptus torelliana* F. Muell. were reservoirs of *A. victoriensis* (Acarina: Phytoseiidae) for adjacent citrus trees and that an understory of Rhodes grass, *Chloris gayana* Kunth provided a supplementary food source in the form of wind-blown pollen. Grass that was infrequently mowed/mown had greater numbers of *A. victoriensis* in the canopy of the citrus trees. In some cases predatory mites led to better control of the mites than the pesticides. Stands of the French prune (*Prunus domestica*) adjacent to Californian vineyards were shown to be an overwintering site for *Anagrus epos*, a parasitoid of the grape leafhopper (*Erythoneura elegantula*) (Pickett *et al.*, 1990). These trees harboured the prune leafhopper, *Edwardsiana prunicola*, an alternative host for the parasitoid, *A. epos* (Kido *et al.*, 1984). A significant increase in parasitism of the first but not subsequent generations of the leafhopper was observed (Murphy *et al.,* 1998).

In a cover crop of hairy vetch (*Vicia villosa*) and rye (*Secale cereale*) planted as a cool-season undertorey cover crop in Georgian pecan orchards, mean densities of aphidophagous coccinellids were nearly 6 times greater than in unmown resident vegetation and approx 87 times greater than in mown grasses and weeds (Bugg *et al*., 1990a). The vegetation harboured alternative prey such three sp of aphids and also some species of thrips. Overall there was no difference in aphid numbers in pecan trees that were undersown with the cover crop despite such large numbers of coccinellids being present in the understorey (Bugg *et al.,* 1990a). Stanyard *et al.,* (1997) found no difference in control of European red mite by *Amblyseius fallacis* when compared between treatments with no cover crop and two grass treatments.

In a New Zealand study (Berndt *et al.,* 2002), buckwheat was tested in a vineyard understorey in an attempt to increase parasitism of leafrollers. Significantly more male *Dolichogenidea tasmanica* were caught on yellow sticky traps within buckwheat plots. However, there was no significant difference for female *D. tasmanica* or either sex of *Glyptapanteles demeter*. No difference in parasitism of releases and recaptured *E. postvittana* larvae by *D. tasmanica* was found.

Buckwheat was sown in a New York vineyard in an attempt to increase the parasitism of *Erythroneura* leafhoppers by *Anagrus* wasps (English-Loeb *et al.,* 2003). Despite slight differences in *Anagrus* wasps in the second year of the study in buckwheat plots compared to clover or sod plots, there were no differences in leafhopper numbers. However, parasitism of sentinel leafhopper egg cards was higher on vines with buckwheat compared to clover or sod in the first year of the study but wad not significant in the second year. Cage experiments indicated greater parasitism of leafhopper eggs when adult *Anagrus* had access to buckwheat flowers.

Hanna *et al.* (2003) tested a cover crop of vetch and oats to increase the number of spiders in a vineyard in order to control the leafhopper, *Erythroneura variabilis*. However, while there was a 1.6-fold higher population of spiders in the cover crop plots compared to the cultivated plots there was no effect on the leaf hopper population.

The complexity of tritrophic interactions was illustrated in a New Zealand study where buckwheat was sown in the understories of stonefruit and apple orchards. While 34% parasitism of *Epiphyas postvittana* was observed in buckwheat plots compared to 20% in the bare ground control, an increase in *Anacharis* sp., a parasitoid of the beneficial brown lacewing also occurred (Stephens *et al.,* 1998).

Gruys (1982) compared four 1-ha weedy orchard plots with four clean cultivated orchard plots under IPM. Wild carrot (*Daucus carota*), parsnip (*Pastinaca sativa*) and hogweed were amongst some of the species found in the weedy plots. Species such as European red mite (*Panonychus ulmi*) and its phytoseiid predators; the apple pygmy moth (*Stigmella malella*) and its eulophid parasitoid, *Chrysocharis prodice*; aphids and predacious syrphids; parasitism of *Adoxophyes orana* by the natural population of parasitoids; and parasitism of leafroller species by the released eulophid, *Colpoclypeus florus,* were all assessed. However, no difference was found in the effectiveness of pest control by beneficial arthropods. Nevertheless, an increase in the common green capsid bug, *Lygus pabulinus,* which damages the fruit, did occur in the weedy plots.

Altieri and Schmidt (1985, 1986) compared two closely located organic orchards, one with bell beans (*Vicia faba*) and the other clean cultivated. The orchard that contained bell beans had 36.1% of fruit damaged by codling moth while the clean cultivated orchard had 45.0% of fruit damaged. Although the trial was unreplicated, the use of bell bean extrafloral nectaries by parasitoids has been documented (Bugg and Wilson*,* 1989).

Very little attention has been paid to the issue of cover crop management. Mowing height plays an important role in the determination of groundcover species composition. Frequent low mowing encourages species that produce seeds close to the soil surface such as grasses and species with a rosette architecture such as dandelion. Herbicide treated areas further decrease diversity by selecting for plants that can be regenerated from underground growth such as a strong taproot or rhizomes. Less frequent mowing allows a greater range of herbaceous plants to flower increasing diversity of understorey and the corresponding arthropod population. A study undertaken in Washington State (Horton *et al.,* 2003) demonstrated a significant increase in predators, parasitoids and alternative prey in sweep net samples of cover crops. This increase did translate to an increase in these species within the pear tree canopy but the increase was significant only for spiders and a predatory mirid (*Deraeocoris brevis*).

There are few examples of successful trap cropping. Hokkanen (1991) listed 11 pest species that have been controlled in field crops and gave examples of two successful applications of trap cropping in trees. All examples have been with hemipteran and coleopteran species. He suggested many possible combinations for control of other species. Trap cropping works on the principle that the pest species finds the trap crop more attractive than the cash crop. Pests on the trap crop can be sprayed or destroyed by other methods thereby minimising the amount of pesticide applied to the actual crop. Trap crops may also be a reservoir of natural enemies.

While habitat manipulations in orchards often resulted in the increase of beneficial arthropods within the area diversified/manipulated, it does not always translate into increased numbers within the crop trees. A study carried out in two Georgian pecan orchards by Bugg and Dutcher (1993) exemplifies this point. Cover-cropped plots consisting of mostly *Sesbania exaltata* were grown and provided high densities of cowpea aphid (*Aphis craccivora*) and bandedwinged whitefly (*Trialeurodes abutilonea*) as alternative prey. However, there was no beneficial change in insect numbers in the canopy.

Trapping methods for insects all have some limitations. Attractant traps are likely to trap disproportionate numbers of different species, lifestages within species or males and females of a species. Trapping results can vary with the physiological state of the species. Hickman *et al.* (2001) tested the hypothesis that yellow water-traps are more attractive to hungry hoverflies. They placed traps at two heights in two treatments, one with flowers and one without, at increasing distances from the field edge. In low traps in treatments with and without flowers, there was no difference in the numbers trapped and in the numbers observed (low traps are more hidden). In the high traps there was a significant difference in the numbers observed. When the guts of the hoverflies were dissected to assess the amount of pollen grains, the hoverflies in the high traps had less pollen in their guts than those in low traps. This finding supported their theory that the yellow traps were attracting hungry hoverflies as they associated yellow with food. They cited several examples of habitat manipulation where a converse result was obtained with hoverflies. They also suggested that yellow sticky traps caused the same bias but pointed out that transparent sticky traps caught few hoverflies and that malaise traps were expensive and not very practical, and argued that visual observation of adults and destructive sampling to count larvae are currently the only methods that are not biased. Similar problems are associated with other trapping methods. As a consequence, a variety of trapping methods should be used when assessing invertebrate numbers.

Plant selection

A number of plants keep recurring in the literature as potentially suitable cover crops. These are:

Apiaceae:

- Sweet fennel (*Foeniculum vulgare* Miller var. *dulce* Battandier and Trabut, (Maingay *et al.,* 1991) wasps, Coccinellidae
- Toothpick ammi (*Ammi visnaga*) (Bugg and Wilson, 1989) bell-pepper, Braconidae, Ichneumonidae, Sarcophagidae, Sphecidae, Tachinidae, Vespidae.
- *Aegopodium podagraria*, *Daucus carota* (Wäckers *et al.,* 1996) *Pimpla turionellae.*

Lamiaceae:

- Spearmint (*Mentha spicata* L.) (Maingay *et al.,* 1991).

Based on this desktop study, potential cover crop plant species for this project were selected on the basis of these charactersitics:

- Suitable nectar or pollen source for beneficials and/or host to alternative prey
- Provide shelter and/or overwintering sites
- Resistance to pests and diseases of pome fruit
- Drought tolerance
- Suitable morphology
- Ability to withstand mowing and trampling

Plants were chosen so that flowering was at varying times throughout the year so as to provide a continuous supply of nectar and/or pollen over the apple and pear growing season.

The plant species and families selected for field testing following glasshouse test were

1. Asteraceae: *Chicorium intybus* (chicory) and *Achillea millefolium* (yarrow)
2. Apiaceae: *Foeniculum vulgare* (fennel) and *Ammi majus* (Queen Anne's lace)
3. Brassicaceae: *Brassica napus* (mustard)
4. Polygonaceae: *Fagopyrum esculentum* (buckwheat)
5. Poaceae: *Lolium perenne* (perennial ryegrass, *Festuca arundinacea* (tall fescue)

Materials & Methods

Glasshouse and laboratory trials

A range of potential plant species were screened for their suitability as hosts for lightbrown apple moth. Ideal plant species for cover crops will be unfavourable hosts for lightbrown apple moth. Two screening methods were used:

1. Moth egg laying trials in glasshouse
2. Larval feeding trials in laboratory

A laboratory culture of lightbrown apple moth was reared on a wheat germ-based diet. For the oviposition assays, replicated trials (4 replicates per trial) were established on a glasshouse bench to compare the suitability of a number of test plant species. Mated female moths were released in the small glasshouse cages containing pots of each test plant species. There were four replicates in each experiment. The numbers of egg masses on each pot were assessed by searching each plant for 3 minutes. For larval survival assays, ten neonate larvae were placed on an excised piece of test plant tissue held on moist cotton wool in Solo® cups (5 replicates per treatment). Cups were held in a constant temperature room at held at 19°C. Survival, pupal weight, pupation date and emergence date were recorded.

Plant species tested for oviposition preference by lightbrown apple moth were as follows:

Plant species	**Growth stage**
Experiment 1 — 27 October 2000	
Strawberry, *Fragaria x ananassa*	flowering, fruiting
Swamp foxtail grass, *Pennisetum alopecuriodes*	35 cm fronds
Marigold cv. Pacific Giants, *Calendula officinalis*	buds - flowering
Nasturtium cv. Jewel, *Tropaeolum majus*	flowering
Forage rape cv. Maxima, *Brassica napus*	large seedlings
Lucerne cv. Aquarius, *Medicago sativae*	large seedlings
Vetch cv. Capello, *Vicia sativa*	flowering
Experiment 2 — 28 November 2000	
Strawberry, *Fragaria x ananassa*	pre-flowering
Azalea cv. Kurume, *Rhododendron obtusum*	large seedlings
Marigold cv. Pacific Giants, *Calendula officinalis*	large seedlings
Veronica cv. Georgia Blue, *Veronica peduncularis*	flowering
Lobelia cv. Cambridge Blue, *Lobelia erinus*	flowering
Cotula, *Cotula perpusilla*	seedlings
White clover cv. Prop, *Trifolium repens*	pre-flowering
Experiment 3 — 30 January 2001	
Azalea cv. Kurume, *Rhododendron obtusum*	large seedlings
Viola	large seedlings
Dichondria	15 cm diameter
Forage rape cv. Maxima, *Brassica napus*	large seedlings
Lucerne cv. Aquarius, *Medicago sativae*	large seedlings

In 2001, the LBAM culture was used in additional growth room feeding trials. Fennel, yarrow, buckwheat and strawberry (as a control) were tested by placing neonate larvae onto the test plants. Larval and pupal development time, pupal weight and percentage emergence of moths (a measure of survival) were all recorded. This trial was conducted at 19°C and 14:10 L:D.

Field Trials

2001/2002 Trial Sites

In the 2001/02 growing season, trial sites were established in the Goulbourn Valley (Mooroopna North (36° 26' S, 145 13' W)) and in the Yarra Valley (Silvan (37° 58' S, 145° 24' W) and Templestowe (37° 46' S, 145° 66' W)). Sites were diverse in chemical application practices with Mooroopna North and Silvan being strict and less strict IPM respectively while Templestowe was under organic management practices.

Treatments

Plants were selected based on certain characteristics:

- Suitable nectar or pollen source for beneficials and/or host to alternative prey
- Provide shelter and/or overwintering sites
- Resistance to pests and diseases of pome fruit
- Drought tolerance
- Suitable morphology
- Ability to withstand mowing and trampling

Potential cover crop species were selected using the information in the literature in relation to the above selection criteria.

Once plants with suitable morphology had been chosen, trials were conducted that tested for susceptibility to *Epiphyas postvittana,* light brown apple moth (LBAM), and *Helicoverpa armigera*. Eight plant species were selected representing five families. Plants were tested in family groups to help minimise the large area required for the trial and to identify any family trends that may be present.

The plant species and families selected were

1. Asteraceae: *Chicorium intybus* (chicory) and *Achillea millefolium* (yarrow)
2. Apiaceae: *Foeniculum vulgare* (fennel) and *Ammi majus* (Queen Anne's lace)
3. Brassicaceae: *Brassica napus* (mustard)
4. Polygonaceae: *Fagopyrum esculentum*
5. Poaceae: *Lolium perenne* (perennial ryegrass, *Festuca arundinacea* (tall fescue)
6. 'volunteer' treatment, where weed species were allowed to colonise.

Plants were chosen so that flowering was at varying times throughout the year so as to provide a continuous supply of nectar and/or pollen over the apple and pear growing season.

Trial design

Mooroopna North

The trial was established in a block of Gala apples in an IPM orchard system. There were four repetitions of six treatments, each treatment block being three rows wide (18 m x 16 m). The plots were arranged in a randomised block design.

The trial layout is shown in Figure 1.

Silvan

The trial was established in a block of Fuji apples (12 rows) interspersed with Gala (7 rows) approximately every third row. The orchard was under IPM management. There were four repetitions of six treatments, each treatment block being four rows wide (15 m x 18 m).

The plots were arranged in a randomised block design.

The trial layout is shown in Figure 2.

Templestowe

The trial was established in a block of Bosc pears. The orchard was managed organically - no insecticides, fungicides or herbicides were be applied to this site. A split block design was used to accommodate a 'triangular' shaped block. Each triangular plot was 204 m^2 (12.25 m x 16.1 m).

<u>Site preparation</u>

Trial site preparation was initiated during September and October. At the Mooroopna North and Silvan sites, glyphosate herbicide was applied at label rate to the entire understorey. Three to five days later, a disc plough was passed at least twice over the alleys at all three sites to break up compacted soil followed by a large rotary hoe to create an even seedbed. Seed was mixed with sand to allow even distribution and ease of handling particularly of small seeds when broadcast by hand. Seed was covered with several centimetres of soil using a rotary hoe at Mooroopna North or by raking in by hand at Silvan and Templestowe. Germination was observed from 5 days onwards.

<u>Monitoring of insect populations</u>:

Insect populations were monitored in the tree canopy using yellow sticky traps. At Mooroopna North and Silvan traps were suspended between training wires at so that the traps were at an average height of 1.4 m and 1.3 m for the sites respectively where foliage was of the greatest density. At the Templestowe site, sticky traps were hung between branches so that the traps were at an average height of 1.3 m within the pear trees.

<u>Fruit sampling</u>:

Prior to harvest, fruit was collected for assessment of yield (fruit diameter and mass) and insect damage. Fruit yield (96 fruit per treatment per site) was assessed for the Tatura and Silvan sites, and damage (192 fruit per treatment per site) was assessed at all three sites.

At Mooroopna North on 19 February 2002, three apples were randomly sampled from each of four heights (0.4 m, 1.25 m, 2.1 m and 2.8 m) from both sides of the central alley of each plot. Samples were not taken from the two trees at either end of the plot, thereby excluding 4 m at either end of plot to avoid any edge effects. A total of 24 apples were sampled from each plot taken back to the laboratory for assessment. Apples were weighed, diameter measured and damage assessed within one week of harvest. All fruit were weighed on the same day, as weight is lost with storage.

At Silvan on 25 March 2002, four apples were taken from each of the three heights (0.6 m, 1.5 m and 2.2 m) from both sides of the middle row of trees of each plot. A total of 24 apples per plot were taken back to the laboratory for assessment as per Mooroopna North.

At Templestowe on 5 March 2002, only three of the six treatments were assessed because the remaining three treatments did not satisfactorily establish and, therefore, were heavily infested with weeds. This was largely due being unable to spray herbicides as the orchard was under organic management practices. Pears were sampled from the three middle trees, but not from the tree on the outer edge of the plot on both sides of the alley at three heights (1.3 m, 2.2 m and 3 m) on both rows bordering the central alley of each plot. The diameter, but not weights, of the18 pears per plot were measured *in situ* so that pears could be left on the trees.

All fruit were rated using a 6 point damage scale ranging from 0 for no damage to 5 for severe damage. Type of damage assessed included bird damage, insect damage [LBAM, *Helicoverpa*, apple dimpling bug (ADB), European red mite (ERM), thrips, woolly aphid], disease [apple scab, rot] and physiological damage [stem russet, russet, splitting].

2002/2003 Trial Sites

Three sites were planned.

1. Red Hill (biodynamic) Elstar apple block
2. Harcourt (IPM) Galaxy apple block
3. Merrigum (biodynamic) WBC pear block

The two biodynamic sites were selected to minimise the confounding effects of synthetic pesticides on cover crop-insect/mite population interaction. However, because of the drought, only the Harcourt and Red Hill trials could be successfully established. Unfortunately, the Harcourt site had to be abandoned due to lack of water (cover crops mowed in December), leaving the Red Hill site as the only complete trial for the season.

At Red Hill, there were four repetitions of three treatments, each treatment block being three rows wide (15 m x 17.5 m). The plots were arranged in a randomised block design. The treatments were:

1. fenugreek (Fabaceae)
2. buckwheat (Polygonaceae)
3. volunteer grasses

The Red Hill trial was monitored with sticky traps as for the 2001-2000 trials. Harvest was completed at the field trial site in February 2003. Fruit number, diameter and damage assessments were made.

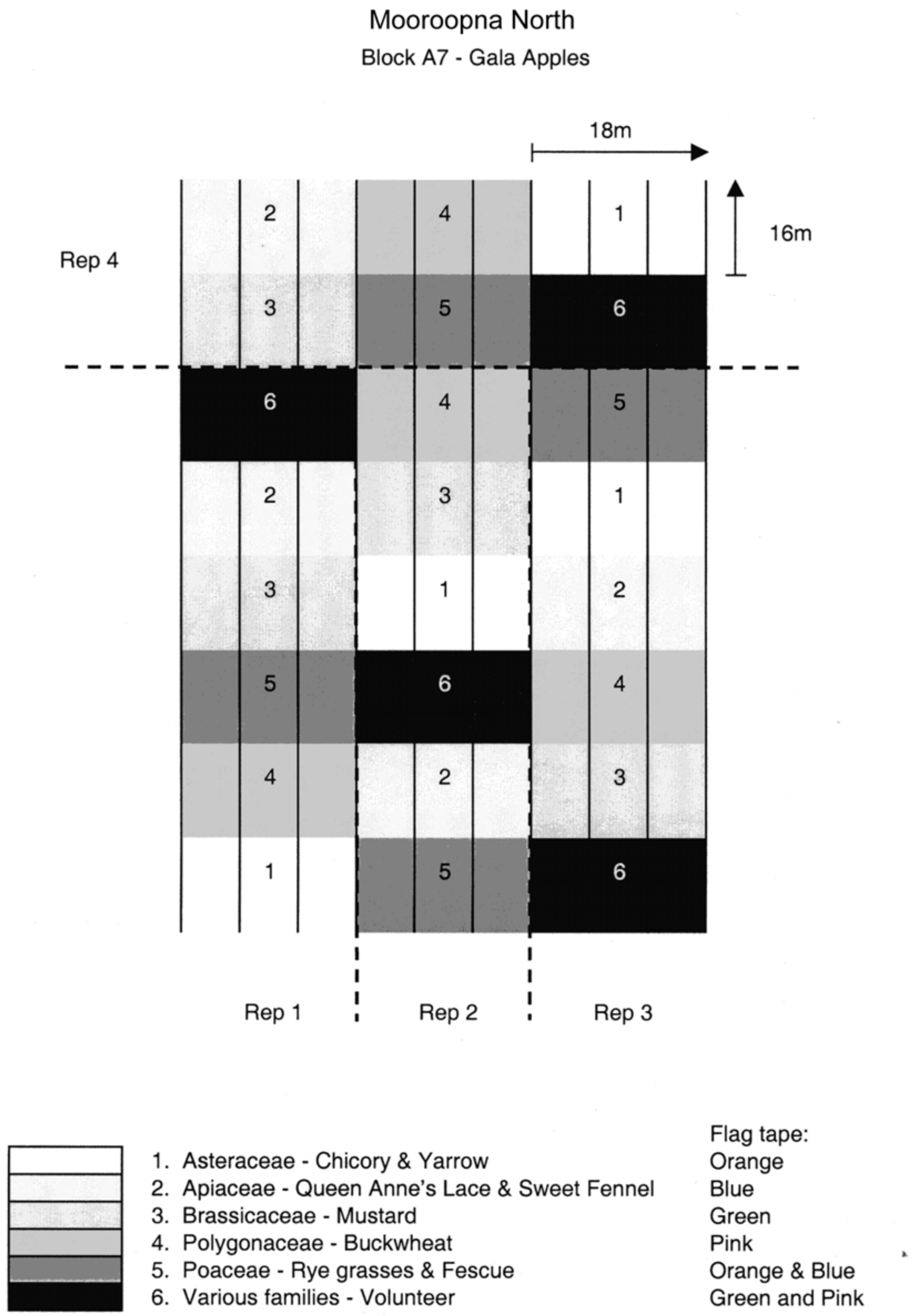

Figure 1 Site plan for Mooroopna North site, 2002-2003

SILVAN SITE PLAN

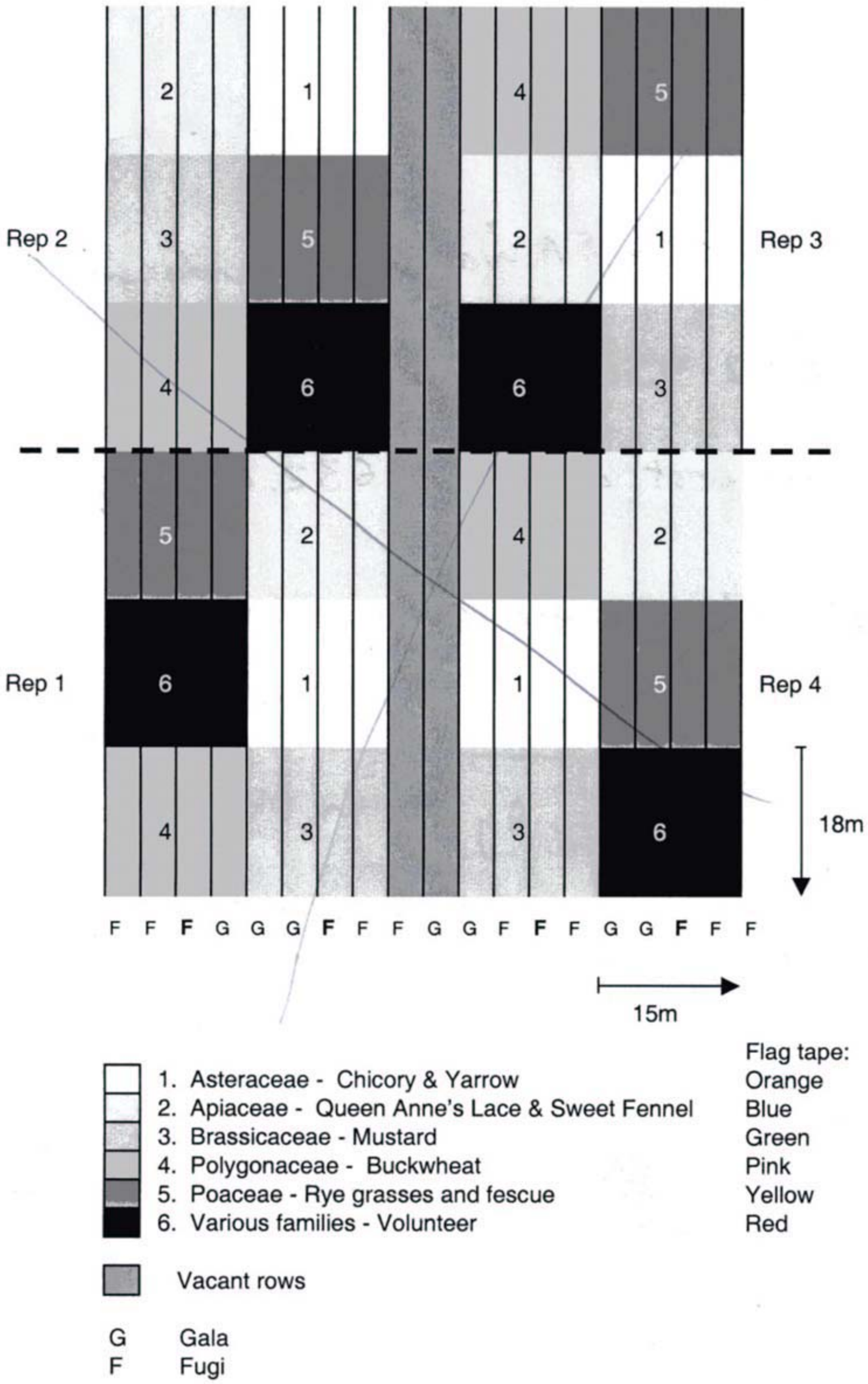

Figure 2 Site plan for Silvan site, 2002-2003

Results

Glasshouse and laboratory trials

In Experiment 1, nearly all egg masses were observed on strawberry (Figure 3). This is also reflected in the number of larvae observed on the strawberry test plants (Figure 4). Very few egg masses were found on the other plants tested: swamp foxtail, vetch, nasturtium, rape and lucerne. Apart from on strawberry, LBAM larvae were only observed in low numbers on nasturtium, lucerne and vetch. This suggested that none of the species tested , apart from strawberry, would act as a source of LBAM if used as cover crops.

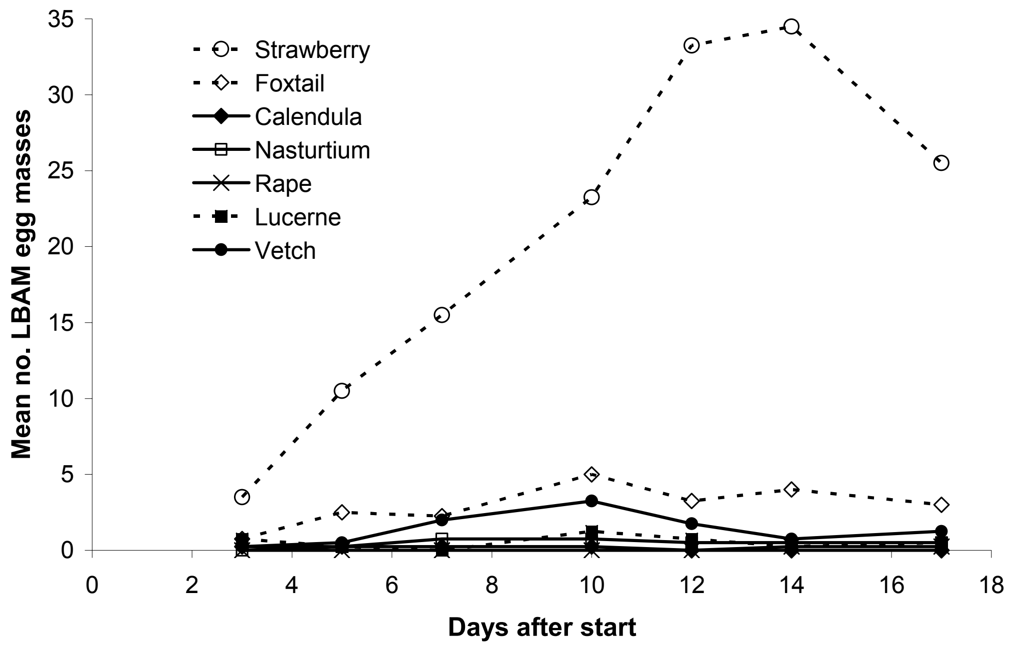

Figure 3 Number of LBAM egg masses found on test plant species (3 minute search per plant). Experiment 1 Glasshouse 13, Knoxfield. Trial commenced 28 October, 2000.

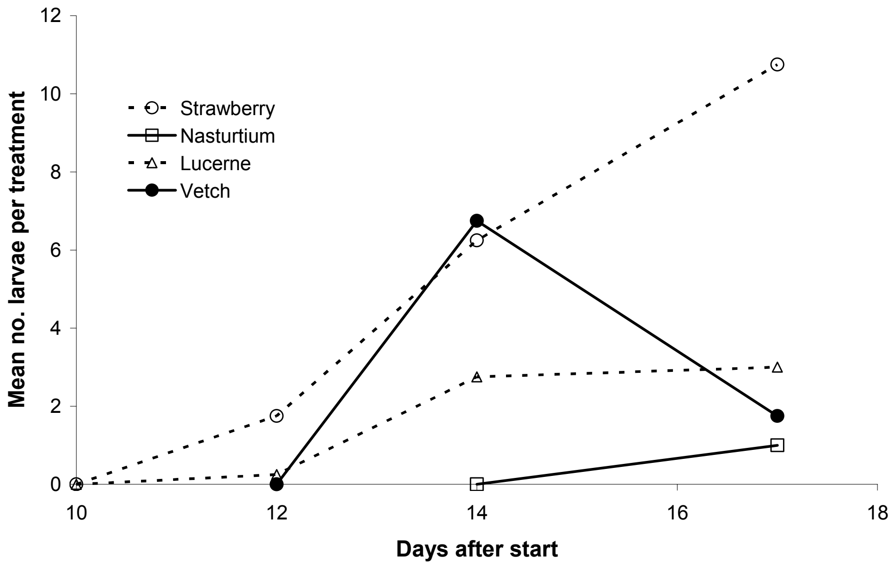

Figure 4 Number of LBAM larvae on test plant species (3 minute search per plant). Experiment 1, glasshouse 13, Knoxfield. Trial commenced 28 October, 2000.

In experiment 2, LBAM egg masses (Figure 5) were most abundant on strawberry and azalea, intermediate numbers were found on veronica and white clover, while numbers of egg masses on *Cotula*, *Lobelia* and *Calendula* were very low. In Experiment 3, numbers of LBAM egg masses were consistently high on azalea (Figure 6), intermediate on *Viola* (with one large peak) and *Dichondria*, and very low on rape, lucerne and strawberry. We can find no explanation for the dramatic reversal of preference for strawberry between Experiments 1, 2 and 3.

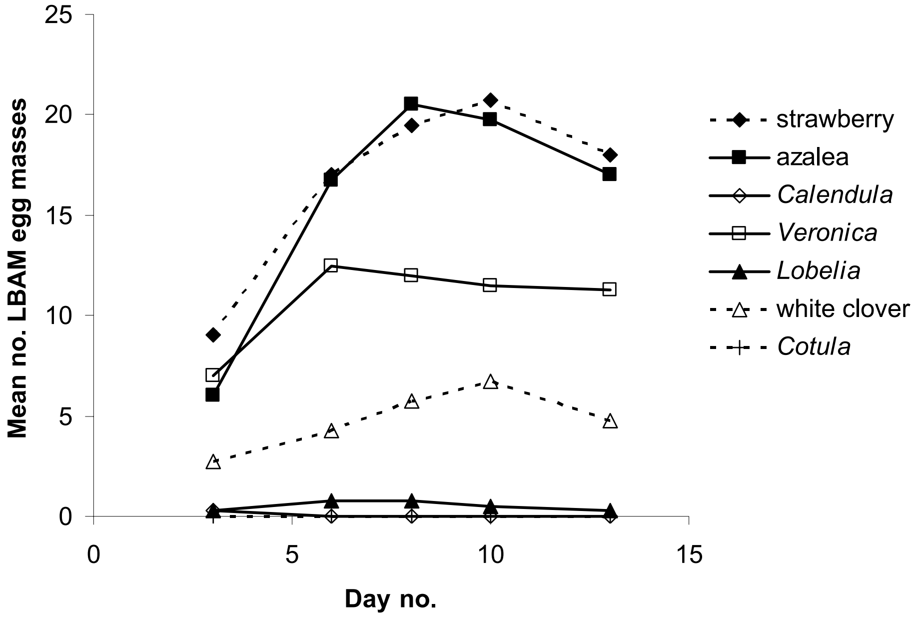

Figure 5	Number of LBAM egg masses found on test plant species (3 minute search per plant). Experiment 2, Glasshouse 13, Knoxfield. Trial commenced 27 November, 2000.

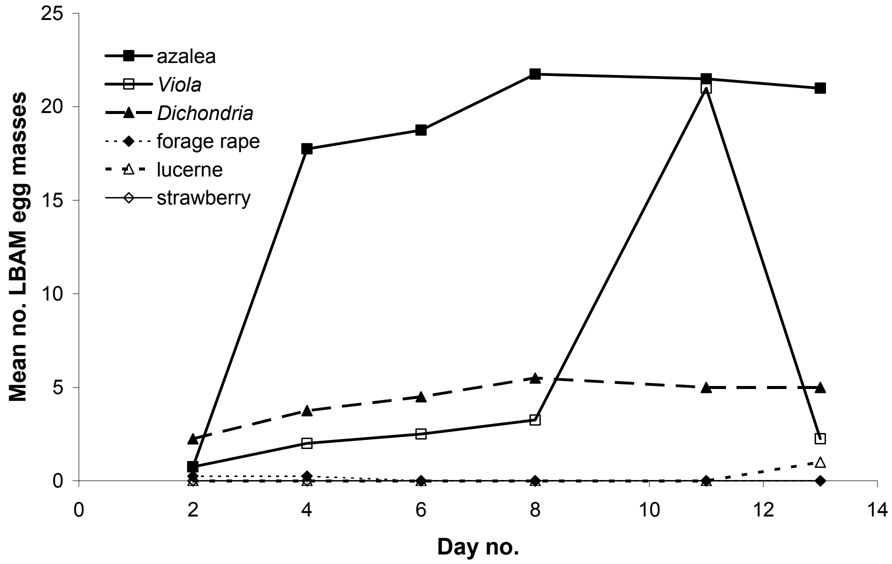

Figure 6	Number of LBAM egg masses found on test plant species (3 minute search per plant). Experiment 3, Glasshouse 13, Knoxfield. Trial commenced 30 January, 2001.

Aphid ratings

In Trial 1 (Glasshouse 13, start date: 27 October 2000), aphids (mainly *Myzus persicae* and *M. ornatus*) were present on *Calendula* at the start of experiment. We took the opportunity to rate the size of the aphid colonies developing on the test plants in this trial. Aphids could provide food for beneficials, directly as prey of lacewings and coccinellids, or indirectly by adult wasps feeding on honeydew.

N = nil: no aphids

L = light: up to a few aphids on some leaves

M = medium: several leaves with aphid colonies

H = heavy: most leaves with large numbers of aphids

Aphid colonies were greatest on *Calendula*, *Brassica* and *Tropaeolum* (Figure 7). This was as expected given the aphid species mainly involved (*Myzus persicae* and *Myzus ornatus*).

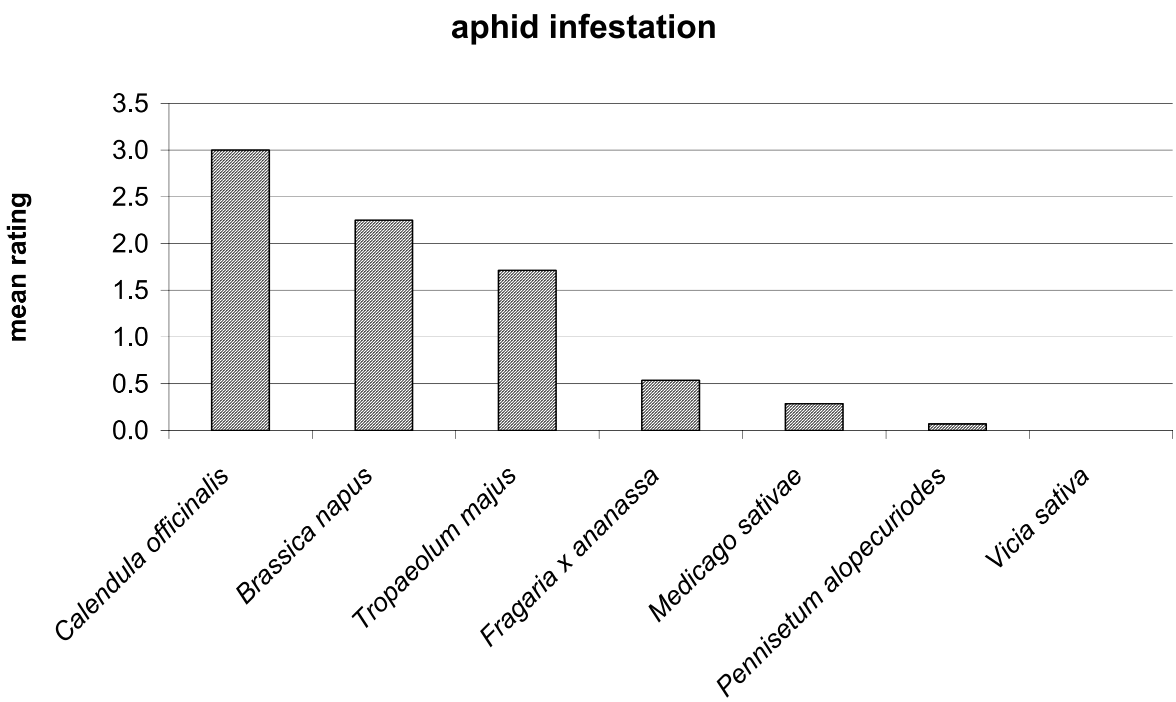

Figure 7 Mean aphid rating found on test plant species. Experiment 1 Glasshouse 13, Knoxfield. Trial commenced 28 October, 2000.

In experiment 4, survival of LBAM larvae was greatest for larvae reared on strawberry. Survival rates were progressively lower for larvae reared on vetch, nasturtium, calendula, and canola. The lowest rate of survival was found with swamp foxtail.

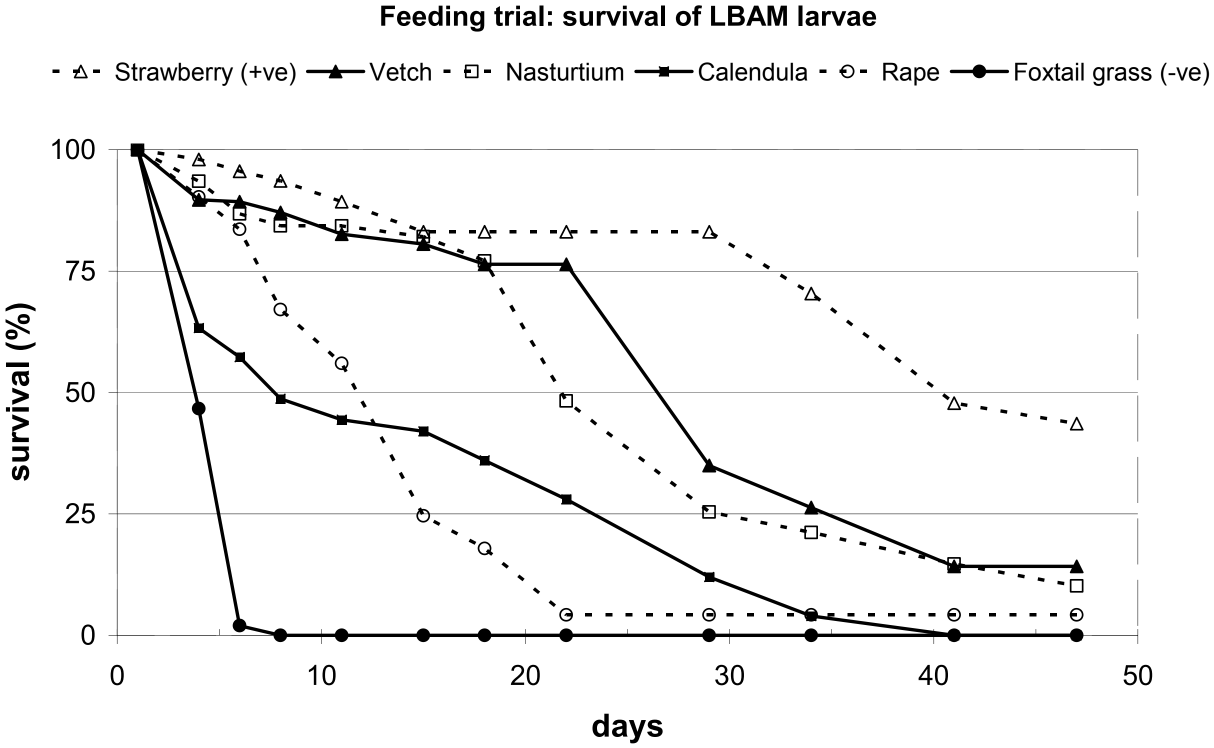

Figure 8 Survival of LBAM larvae on excised leaves of test plants. Trial conducted at 19°C., Experiment 4

In experiment 5, there was a significant difference in pupal weight (Figure 9; $F_{3,11}$=17.57; *P*<0.001) and in immature development time (Figure 10; $F_{3,11}$=24.94) between larvae reared on yarrow, fennel, buckwheat and strawberry. LBAM developed longer but had a lower pupal weight on strawberry than the other hosts, which suggested that it was in fact an inferior host for LBAM. Irrespective of host plant, there was a significant but weak relationship (r^2=0.0978) between development time and pupal weight (Figure 11).

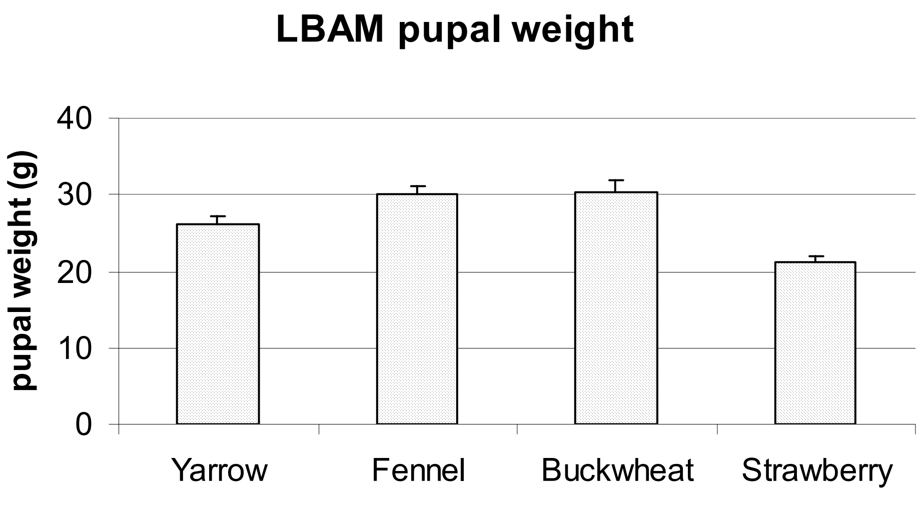

Figure 9 Pupal weight (g) of LBAM after developing on four host plants. Trial conducted at 19°C., Experiment 5

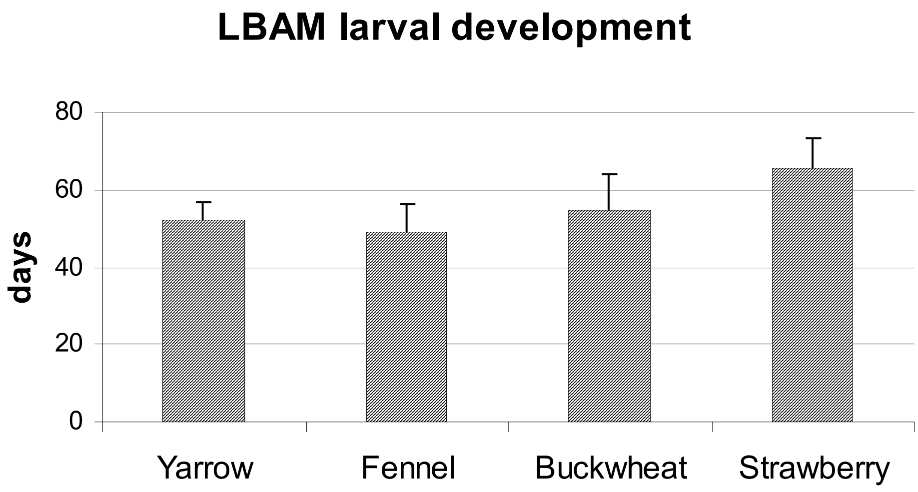

Figure 10 Length of larval development (days) of LBAM after developing on four host plants, Trial conducted at 19°C., Experiment 5.

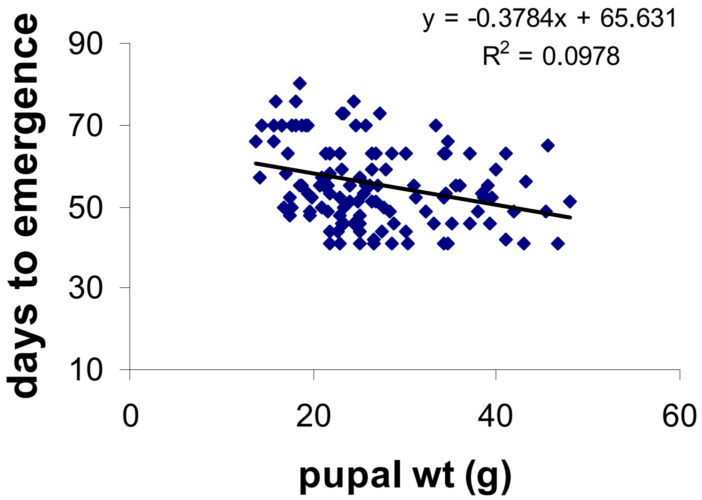

Figure 11 Relationship between pupa weight and total immature development for LBAM reared on four host plants (data pooled) (yarrow, fennel, buckwheat and strawberry). Trial conducted at 19°C., Experiment 5.

Results summary (egg laying trials):

On the basis of these glasshouse trials with LBAM together with some preliminary assessments of larval suitability for *Helicoverpa armigera*, conclusions on suitability of plants for use in cover crops in pome orchards are listed below.

Poor hosts (potential cover crop species)
Swamp foxtail grass
Canola
Lucerne
Vetch
Calendula
Nasturtium
Lobelia
Cotula
Viola

Marginal hosts (possible cover crop species)
White clover
Dichondria

Good hosts (unsuitable cover crop species)
Strawberry (+ve control)
Azalea
Veronica

Results summary (larval survival trials):

Poor hosts (potential cover crop species)
Swamp foxtail grass
Lucerne
Calendula
Nasturtium
Canola
Veronica
Cotula

Marginal hosts (possible cover crop species)
Vetch
Nasturtium
White clover

Good hosts (unsuitable cover crop species)
Strawberry (+ve control)
Lobelia

Field Trials

Fruit Yield

Fruit weight and fruit diameter were significantly affected by treatment at Mooroopna North (*P*=0.005) and marginally affected by treatment at Silvan (*P*=0.046) (Table 1). At Mooroopna North, the apple weight and diameter was greatest for the chicory/ yarrow treatment while the Queen Anne's lace /fennel treatment resulted in the smallest and lightest fruit (Figures 12, 13). While the difference between these two treatments was statistically significant, there were no statistical differences between any other combinations of treatments. At Silvan the buckwheat, ryegrass and fescue and the chicory and yarrow treatment produced the largest and heaviest fruit while the Queen Anne's lace/fennel and also the mustard treatments resulted in the lightest apples. These results show that, when compared to the volunteer weeds (control), the cover crops did not cause nutrient or water stress to their adjacent trees. At the Templestowe site, neither fruit weight nor fruit diameter showed significant variation over the treatments. This is probably because of poor cover crop establishment due to several factors:

- competition with weedy species as no herbicide sprays could be applied,
- soil preparation was insufficient due to use of tractor of inadequate horse-power,
- the cover crops were sown several weeks too late.

	Mooroopna North	Silvan	Templestowe
	apple weight (g)	apple weight (g)	pear length (mm)
Asteraceae	186.2±3.52	184.1±3.57	NA
Apiaceae	168.7±3.47	181.4±3.77	107.4±2.94
Brassicaceae	171.5±3.84	173.1±3.80	NA
Polygonaceae	182.2±3.92	185.5±3.58	111.5±2.72
Poaceae	176.0±4.19	185.6±4.10	NA
Volunteer species	182.1±3.78	173.9±3.80	109.17±3.76
F	3.370	2.277	1.657
P	0.005**	0.046*	0.193

*, ** denotes significance at $P \leq 0.05$, $P < 0.01$ respectively

Table 1 Mean weight and standard error of apples (g) and mean length and standard error of pears (mm) harvested from each treatment at Mooroopna North, Silvan and Templestowe, respectively.

	Mooroopna North	Silvan	Templestowe
	Fruit diameter (mm)		
Asteraceae	75.6±0.53	76.6±0.53	NA
Apiaceae	72.6±0.55	74.9±0.48	65.96±1.10
Brassicaceae	73.2±0.55	74.4±0.55	NA
Polygonaceae	73.8±0.90	75.7±0.50	67.06±1.04
Poaceae	73.4±0.64	75.1±0.54	NA
Volunteer species	74.5±0.57	74.4±0.57	66.76±1.18
F	2.892	3.242	1.06
P	0.014*	0.007**	0.348

*, ** denotes significance at $P \leq 0.05$, $P < 0.01$ respectively

Table 2 Mean diameter and standard error of apples and pears (mm) harvested from each treatment at Mooroopna North, Silvan and Templestowe, respectively.

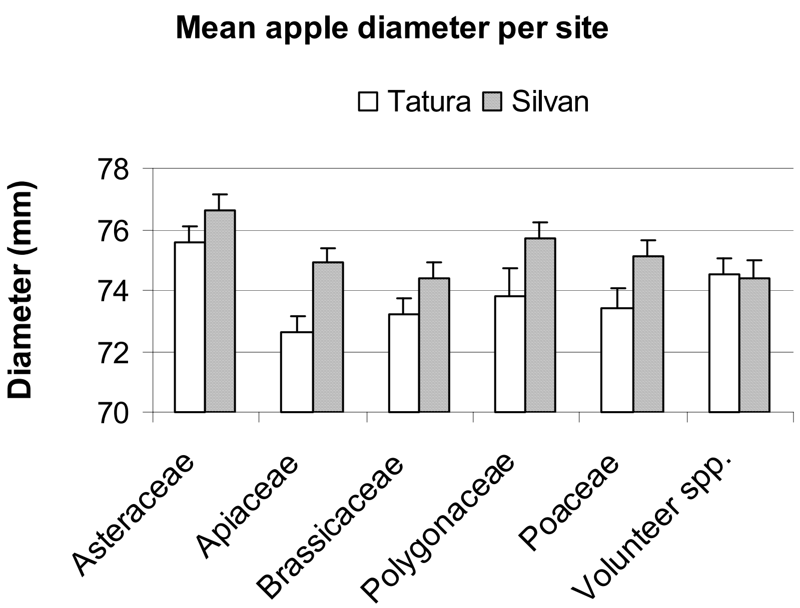

Figure 12 Mean diameter of apples (mm) harvested from each treatment at Mooroopna North and Silvan. Standard error bars are given for each treatment.

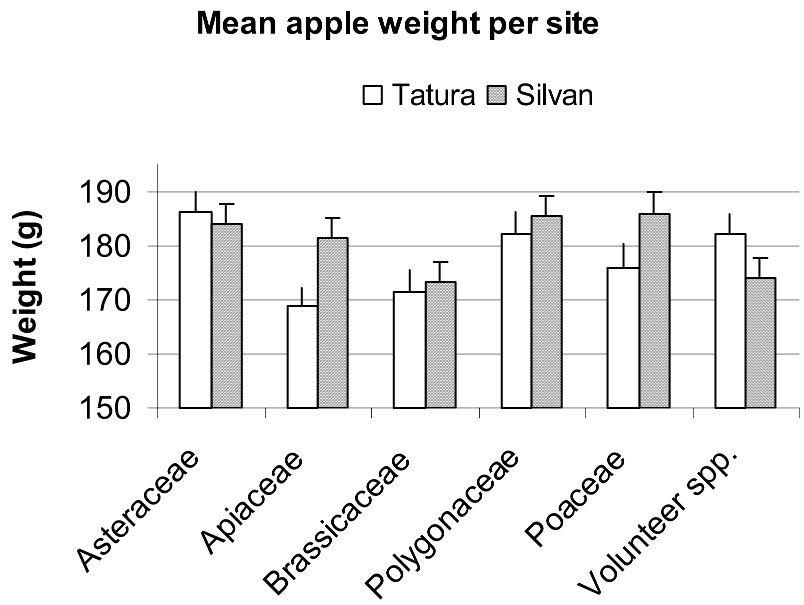

Figure 13 Mean weight of apples (g) harvested from each treatment at Mooroopna North and Silvan. Standard error bars are given for each treatment.

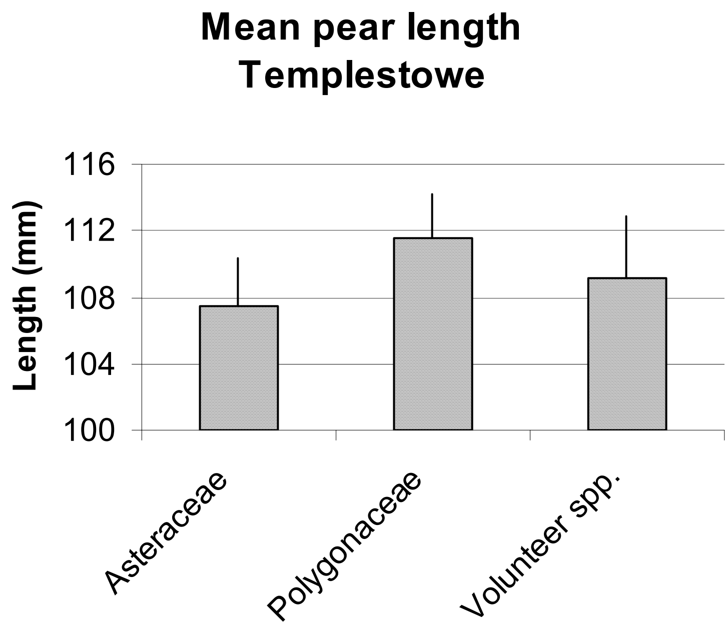

Figure 14 Mean length of pears harvested from each treatment at Templestowe, 2001-2002. Standard error bars are given for each treatment.

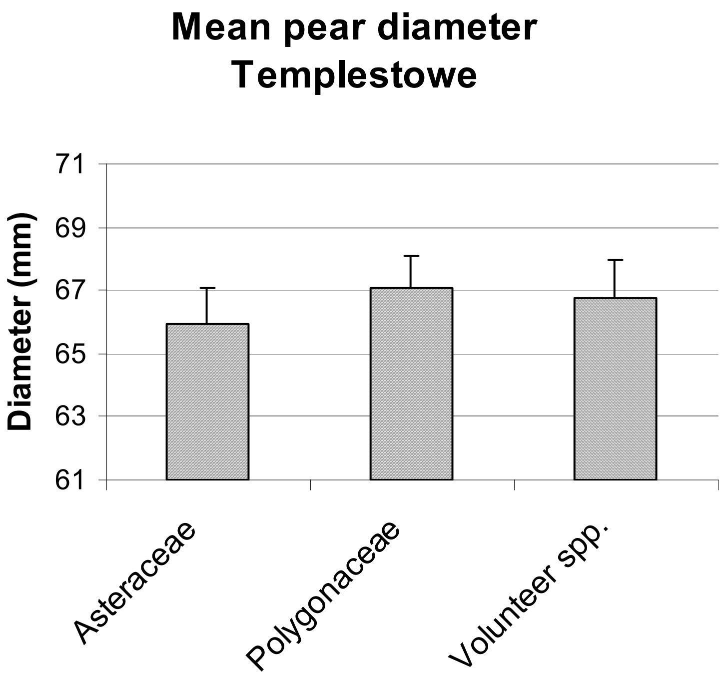

Figure 15 Mean diameter (mm) of pears harvested from each treatment at Templestowe, 2001-2002. Standard error bars are given for each treatment.

At Red Hill, yield was estimated by measuring the diameter of each fruit (Figure 16), a statistic highly correlated to apple weight. Analysis of variance showed no significance difference in fruit diameter between treatments (P=0.089). No differences were observed between any treatments (treatment 1 = grass control; 2= fenugreek (Fabaceae=legume); 3= buckwheat (Polygonaceae). A low level of pest damage was observed throughout all treatments. This is probably associated with dry conditions and grower practices. Overall, there was a strong exponential relationship between number of apples and trunk circumference (r^2=0.737) (Figure 17).

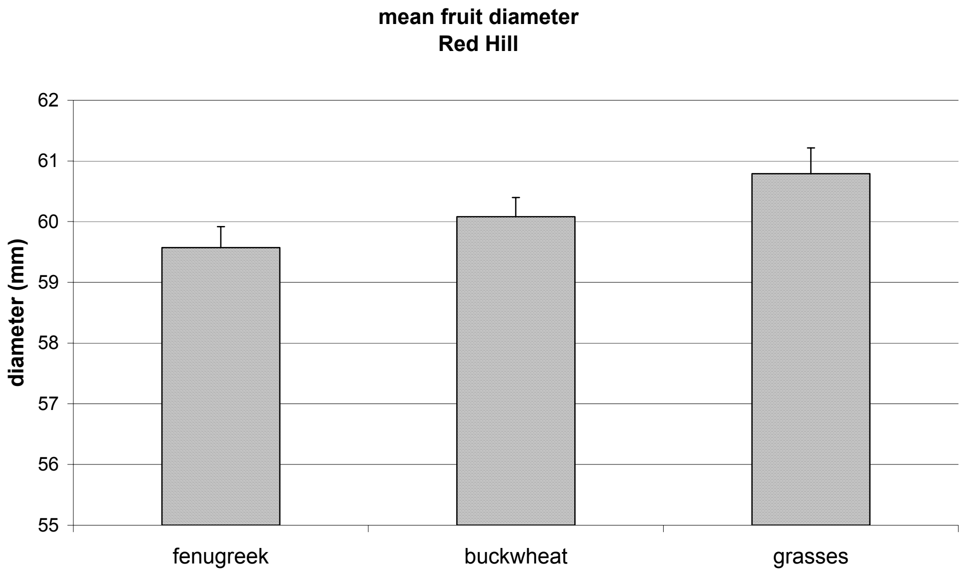

Figure 16 Mean diameter (mm) of apples harvested from each treatment at Red Hill, 2002-2003. Standard error bars are given for each treatment.

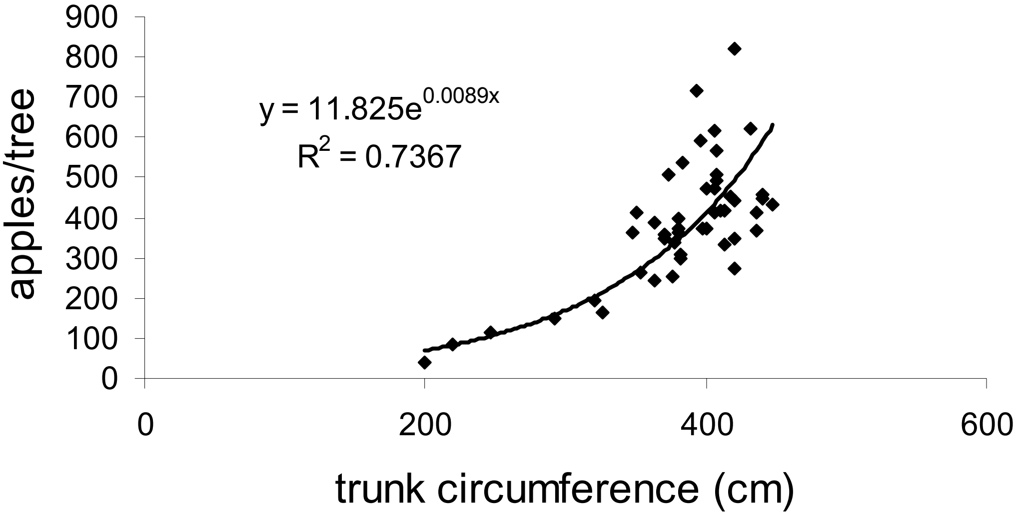

Figure 17 Relationship between trunk circumference and estimated number of apples per tree at Red Hill, 2002-2003 (all data pooled).

Fruit Damage

At both the Silvan and Mooroopna North sites, russeting was the most common form of damage (Figures 18, 19). A 2-sided Monte Carlo analysis indicated highly significant differences between treatments for russet damage at the Mooroopna North site (*P*=0.006) where the mustard and the ryegrass/ fescue treatments resulted in the greatest and least amount of russeting respectively. However, at Silvan the amount of russeting was not significantly different between treatments (*P*=0.97). It is possible that the russet may have been partly induced by the relatively tall canopies of the cover crops which maintained higher relative humidity (RH) in those plots. High RH and slow drying conditions are known to be associated with the development of russet.

Apple dimpling bug (ADB) caused the second greatest amount of damage but between treatments were not significant at either Silvan (*P*=0.86) or Mooroopna North (*P*=0.54). European red mite damage at Silvan varied significantly between treatments (*P*=0.01). No other damage type varied significantly between treatments at either of the sites. The numbers of fruit damaged at the Templestowe site were too low to be analysed despite the site being under organic management.

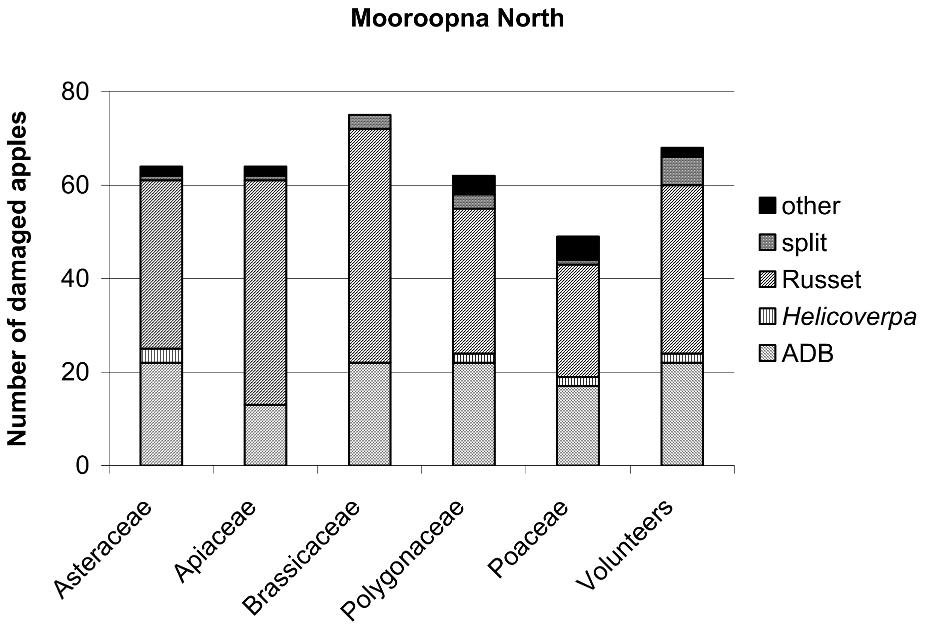

Figure 18 Damage categories to apples at Mooroopna North, 2001-2002

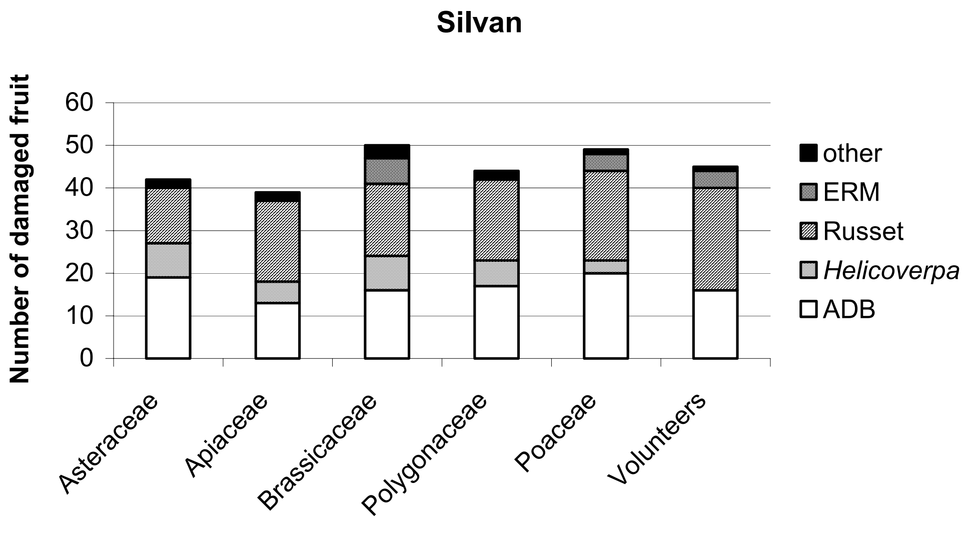

Figure 19 Damage categories to apples at Silvan, 2001-2002

Insect populations
Brown lacewing (*Micromus tasmaniae*) populations were not significantly different over the six treatments at either SIlvan or Mooroopna North, while green lacewing (*Mallada signata*) numbers were too low over all plots to be analysed. At Silvan, more European red mites were found to be overwintering on apples in three treatments: Brassicaceae, Poaceae and volunteer treatments (*P*=0.01) than in the other treatments. In 2002-2003 at Red Hill, lacewings were caught in low numbers but no differences between treatments were found.

Despite trapping large numbers of thrips at Red Hill, there were no significant differences between treatments (Figure 20). Overall, there were no significant differences between treatments (P=0.624) during the season. Transformed data ($\log_{10}(x+1)$) were analysed as a general linear model (Table 3).

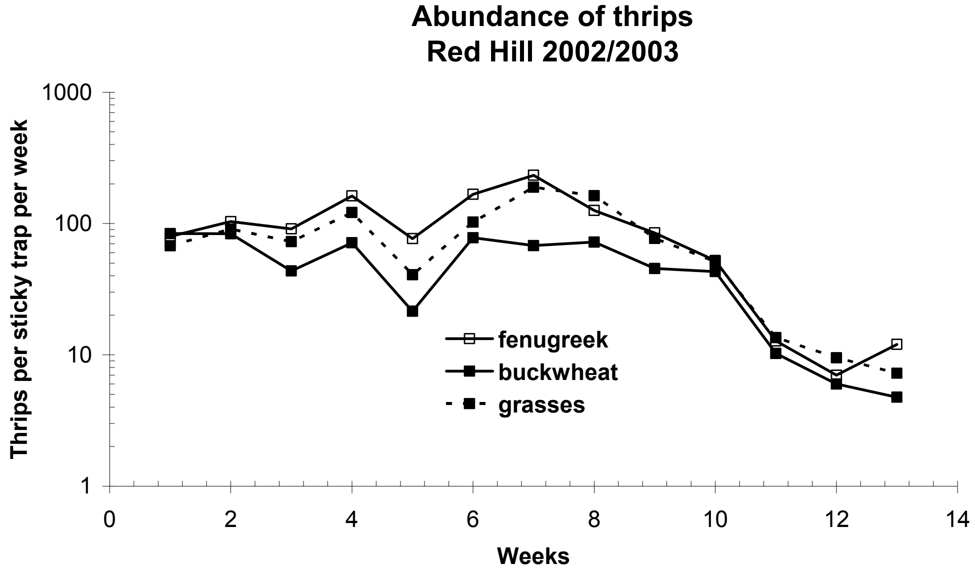

Figure 20 Thrips caught in sticky traps at Red Hill, 2002-2003.

Source	Type III Sum of Squares	df	Mean Square	F	*P*
Intercept	826367.410	1	826367.410	16.072	.007
TREAT	52476.013	2	26238.006	.510	.624
REP	133437.462	3	44479.154	.865	.509
Error	308500.808	6	51416.801		

Table 3 ANOVA table for analysis of pooled thrips catches. Transformed data ($\log_{10}$ (x+1) were analysed as a general linear model.

Discussion

There were major logistical difficulties encountered during these field trials. We had great trouble establishing effective ground cover plots on the sites being grown under biodynamic principles. Without the use of herbicides, many of the plots became overrun with weeds and establishment of the test cover crops was unsatisfactory. Because of the severe drought in 2002/2003, several of the sites had to be curtailed because the growers were unable to water the cover crops beyond December.

With hindsight, the project was too ambitious in terms of the resource requirements for running six fully replicated field trials, with replicates of a sufficient size to minimize inter-plot interactions. Consequently, the difficulties experienced in establishing satisfactory cover crop plots compromised our ability to assess adequately the influence of these cover crops on arthropod populations.

Nevertheless, the project did produce a number of useful outcomes in terms of identifying cover crops. Clearly some cover crops should be avoided because of their potential to be a host to LBAM. This includes plants like azalea and clover. Nevertheless, there are also a number of candidate plants that could act as suitable cover crops. Where seasons are favourable in terms of rainfall, it should be possible to establish cover crops such as buckwheat, fescue and chicory. However, drought conditions limit the usefulness of such cover crops, and weed establishment makes it difficult to establish cover crops that will persist from year to year. Although the cover crops used in this work have been used by other researchers, they may not be suitable for Australian conditions except in some areas with reliable rainfall. Also it has proven difficult to directly demonstrate an effect of cover crops on numbers of pests in trees. This was mostly due to low pest pressures but the active movement of beneficials from the cover crops to the trees remains to be established.

The research also demonstrates that the secondary effects of cover crops need to be carefully considered. The significant differences in fruit characteristics when different cover crops were present were likely to have arisen from factors unrelated to pest damage, as pest pressures were low and differences between treatments in pest numbers could not be established. Instead the presence of cover crops could have influenced water availability to the trees. There were also secondary effects related to russeting, which appears to have been promoted by the taller cover crops.

Given these types of problems, it may be better to focus on vegetation manipulation in shelterbelts surrounding orchard blocks when promoting beneficials. Shelterbelts are ubiquitous in areas with orchards and can provide shelter for large numbers of beneficial insects and mites. For relatively mobile beneficials such as lacewings, parasitoid wasps, predatory flies and ladybeetles, there is the potential for higher numbers of beneficials in shelterbelts to have a direct beneficial effect on pests in orchards. Changes in management in shelterbelts are also unlikely to result in problems due to competition for water and other resources.

Technology Transfer (Milestone 8)

Orchard habitat management. Article in "IHD Links," newsletter of the Institute for Horticultural Development, No. 4, July 2001.

Presentation of research aims, results and direction to staff and students at La Trobe University, Bundoora. Nicole Bone, PhD student, 15 August, 2001.

Presentation of research aims, results and direction to southern Victorian pome fruit growers (Cropwatch group) at Institute for Horticultural Development, Knoxfield. Peter Cole, Project Leader, 4 September, 2001.

Discussions and trial site evaluations with Dr Doug Landis, Director of Centre for Integrated Plant Systems, Michigan State University, USA, were held during his visit to IHD Knoxfield, 13-15 February, 2002.

Discussions with Dr Peter Lo, an entomologist from HortResearch at Hawke's Bay Research Centre located at Havelock North, New Zealand were held during his visit to IHD Knoxfield (18/04/02). We discussed issues in relation to Dr Lo's new project involving assessment of pest and beneficial insect and mite populations on existing understorey plantings in New Zealand and also in relation to this project.

Poster entitled "The impact of various novel cover crops on pome fruit damage and yield" was prepared by Nicole Bone for display at DPI, CESAR and industry conferences.

Recommendations

Further research is needed before unequivocal recommendations can be made to industry about the deployment of cover crops for promoting natural enemy abundance. Firstly, the most important natural enemies need to be identified in order for the appropriate floral characteristics to be established for selecting the most useful cover crops. This is likely to require the development and use of molecular markers to provide a much deeper understanding of the roles of potential predators. Secondly, it is vital to have a better knowledge of movement patterns of arthropods (both pest and natural enemies) between the orchard trees and the cover crops. It is important to establish whether a particular cover crop is acting as a source or sink of natural enemies. Thirdly, the agronomic costs and benefits of the cover crops on the orchard trees must be fully assessed. The increased use of trickle irrigation of the fruit trees means that the cover crops will now require additional specific irrigation in summer to survive. Under older irrigation systems, the cover crops shared the water with the trees.

Acknowledgments

We acknowledge financial support from Apple and Pear Australia Limited, Horticulture Australia Limited and Department of Primary Industries, Victoria.

We thank the co-operating growers (Ian Bolitho, Steven Chapman, Linton Greenwood, Neville Mock, Colin Pickering, Jason Alexandra and Melbourne Water) for allowing us to conduct field trials on their properties.

We thank Steve Whitmore, David Lopez and Francesca Richardson for their technical support at different stages during the project; Mali Malipatil for assistance in identification of trapped insects; Andrew Henderson for his assistance with the media summary.

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