AN ABSTRACT OF THE THESIS OF

Micaela Ruth Colley for the degree of Master of Science in Horticulture presented on March 30, 1998. Title: Enhancement of Biological Control with Beneficial Insectary Plantings.

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John M. Luna

Five field experiments were conducted to evaluate the relative attractiveness of potential beneficial insectary plants to aphidophagous hover flies and parasitic Hymenoptera and the effectiveness of interplanting selected flowering plants in a broccoli field to enhance biocontrol of the cabbage aphid and green peach aphid.

In 1996 we established a preliminary screening trial to begin development of our sampling methods and evaluations of the attractiveness of selected flowering plants to hover flies and parasitic Hymenoptera.

In 1997, we conducted a field experiment at the Oregon State University Vegetable Research Farm near Corvallis, OR to assess the relative attractiveness of 11 selected flowering plants to hover flies and parasitic Hymenoptera. Six of these plants were also evaluated for attractiveness to aphidophagous hover flies in two on-farm trials. The experimental design was a complete randomized block design, with four replications at the OSU site, and three replications at the two on-farm sites. Attractiveness of flowering plants to hover flies was assessed by conducting weekly timed observations of feeding frequencies. Associations of parasitic Hymenoptera

were assessed by weekly timed vacuum sampling from a fixed area in plots of flowering plants.

Attractiveness differed by dates and sites. Among early-season flowering species, *Coriandrum sativa* (cilantro) was highly attractive to aphidophagous hover flies and *Brassica juncea* (mustard), *Fagopyrum esculentum* (buckwheat) and *Agastache rugosa* (Korean licorice mint) were most attractive to parasitic Hymenoptera. Among late-season flowers, *Achillea millefolium* (yarrow), *Foeniculum vulgare* (fennel) and *Agastache rugosa* (Korean licorice mint) were most attractive to hover flies, but attractiveness to parasitic Hymenoptera did not differ.

An on-farm trial was conducted in 1997 at Stahlbush Island Farm near Corvallis, OR. The objective of this trial was to test the hypothesis that interplanting either alyssum (*Lobularia maritima*), or cilantro (*Coriandrum sativa*), with broccoli (*Brassica oleracea*) would attract aphidophagous hover fly adults and parasitic Hymenoptera, enhance oviposition in the adjacent crop, and increase larval predation and parasitism in the adjacent crop, resulting in suppressed cabbage aphid (*Brevicoryne brassicae*) and green peach aphid (*Myzus persicae*) populations in the broccoli crop. The predominate hover fly species present were *Toxomerus occidentalis* and *T. marginatus*. More adult female *T. occidentalis* were caught in pan traps in plots with alyssum than in cilantro or control plots. More hover fly eggs were found on broccoli leaves and a higher percent of the aphids present were parasitized by Hymenoptera in plots with alyssum than in cilantro or control plots. However, no differences in aphid intensities were found between treatment and control plots. A comparison between the mean number of hover fly eggs found per broccoli leaf and the mean number of aphid counted per broccoli leaf suggests there is an association between the two. There appears to be an aphid density threshold below which few hover fly eggs are laid. Gravid females were present in the crop from the first sampling date on, yet hover fly eggs were not found in the crop until the second to last sampling date. Our results indicate that the presence of alyssum enhanced hover fly activity, but did not result in increased larval predation on aphids in the crop.

In 1997 a survey of hover flies was conducted at each of the four experimental sites. Hover flies were captured with sweep nets. Representative specimens were identified to species by Christian Kassebeer, University of Kiel, Germany and subsequent identifications were made from reference specimens and with taxonomic keys. Twenty species were identified, 16 of which are aphidophagous. At the OSU site and the two on-farm sites, where the relative attractiveness of flowering plants was assessed, the six most common aphidophagous species, collected at all three sites, were: *Meliscaeva cinctella, Toxomerus marginatus, T. occidentalis, Sphaerophoria sulphuripes, S. pyrrhina,* and *Scaeva pyrastri*.

Enhancement of Biological Control

with Beneficial Insectary Plantings

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Micaela Ruth Colley

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Major Professor, representing Horticulture

Head of Department of Horticulture

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Micaela Ruth Colley, Author

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A Review of the Literature

Introduction

Beneficial insectary plantings, a form of natural enemy augmentation, offer a promising opportunity to enhance the effectiveness of biological control in integrated pest management systems. For the purpose of this review, the term "beneficial insectary" is being used as the intentional planting of flowering plants in or around farm fields to increase natural enemy abundance and efficiency. Many species of insect predators and parasitoids rely on pollen and nectar for their survival and reproductive success (Schneider, 1948; van Emden, 1962). Two examples of such insect groups are hover flies (Diptera: Syrphidae) and several species of predatory and parasitic wasps (Hymenoptera). Surveys of weed and wild plant compositions in agroecosystems have associated florally abundant non-crop habitat with significantly higher numbers of pollen and nectar feeding natural enemies in and around farm fields (Cowgill 1989, Cowgill et al. 1993) and orchards (Leius 1967). Many farmscapes however are florally impoverished and in such conditions the benefit of these insects may be of limited value. Some preliminary research has demonstrated the potential of planting flowers in and around farm fields to increase local numbers of pollen and nectar feeding natural enemies and lead to reduced pest populations (Kloen and Altieri 1990, White et al. 1995, Hickman et al. 1996).

Habitat Manipulation for Natural Enemies

The hypothesis that increasing vegetational diversity in agroecosystems increases insect pest suppression has been debated extensively. Both supportive and contradictory examples exist in the literature including van Emden and Williams (1974), Murdock (1975) and Altieri and Letourneau (1992). Much of the focus on the topic has surrounded two possible hypotheses proposed by Root in (1973) including; 1) the natural enemies hypothesis, that more diverse agroecosystems support higher numbers of natural enemies which keep herbivorous insect populations in check, and 2) the resource concentration hypothesis, that simple agroecosystems have concentrated resources that specialist herbivores can more easily exploit than more complex agroecosystems.

Studies of the relationship between diversity and stability are numerous and beyond the scope of this current project. However, the theoretical support for enhanced pest control through habitat manipulation is based on promoting the activity of Root's "natural enemies", though not necessarily directly linked to increasing diversity. Many researchers, having assessed the diversity/stability question, have concluded that careful planning to promote "a little powerful diversity" (van Emden and Williams 1974) or "the right kind of diversity" (Way 1966) may be a more effective approach to achieving stability in agricultural systems than haphazardly seeking diversity for diversity's sake.

Wratten and van Emden (1995) have suggested that habitat manipulation practices which are based on knowledge of predators' and parasitoids' ecology rather than "diversity per se" may be a more effective approach toward enhancing natural enemy activity. Approaches discussed by Wratten and van Emden include field margin management and the creation of within - field refugia. The basis of such an approach is to provide for natural enemies "appropriate physical or biotic resources where they have been removed or depleted" (Wratten and van Emden 1995). Habitat manipulation which enhances the availability of pollen and nectar, a biotic resource of many natural enemies, is the focus of this research and the discussion which follows.

Floral Resources and Natural Enemies

Reviews of the role flowers can play in enhancing parasitoid activity have been presented by Powell (1986) and in enhancing Hover fly activity by Wratten and van Emden (1995). Pollen serves as a source of protein and provides amino acids required for sexual maturation (Schneider 1948). Nectar serves primarily as an energy resource providing carbohydrates for these beneficial insects.

Adult hover flies and parasitic wasps exhibit a high degree of selectivity for the flowers from which they feed (Leius 1960, Gilbert 1981, Cowgill 1989, Cowgill et al. 1993). Attractiveness also differs between males and females, probably due to varied resource needs (Hickman and Wratten 1996). Female hover flies tend to feed on more pollen than males and males tend to feed on more nectar than females (Gilbert 1981). The relative qualities of different pollens influence fecundity rates in hover flies (Ankersmit et al. 1986).

Gilbert (1985) reported a diel activity pattern in hover flies. He found that feeding from pollen occurred throughout the day, but hover flies feed almost exclusively from pollen in the morning. Nectar feeding increased to a peak during midday. It was noted that this periodicity coincided with peaks in floral production of nectar, but may also be attributed to thermal regulation of the hover fly.

Morphology of the flowering parts of plants has been observed to effect feeding ability of hover flies, an effect which differs from species to species (Gilbert 1981). Ruppert and Molthan (1986) identified open blossom morphology as facilitating feeding for many of the smaller hover flies. They also refer to flowers of the families Apiaccae, Asteraccea, Brassicaccae and Rosaccae as having a "suitably open" morphology. A deep corolla has been noted to restrict nectar feeding from *Phacelia tanacetifolia* (Harwood et al. 1994). However, the pollen of *P. tanacetifolia* is noted as being readily accessible by Hickman and Wratten (1996) due to the extension of its stamen beyond the ends of the flowers. Conversely the nectar of Cilantro (*Coriandrum sativa*) is readily available, due to shallow corolla, but the pollen was fed from at lower rates when compared to P. tanacetifolia feeding (Hickman et al., 1995).

Color is one factor which has been attributed to the relative attractiveness of certain flowers. Lunau and Wacht (1994) demonstrated that hover flies are strongly attracted to the color yellow. In the laboratory hover flies were exposed to artificial flowers reflecting different color lights. When presented with yellow or green lights hover flies extended their proboscis, a behavior associated with feeding. When presented with ultra violet or blue light proboscis extension was strongly inhibited. *Phacelia tanacetifolia*, however, has a blue flower and hover fly foraging has been repeatedly demonstrated with this plant (e.g. Hickman and Wratten, 1996), suggesting that other factors play significant roles in attractiveness other than color.

Floral resources are utilized by a diversity of families of natural enemies, the implications of which have not been fully explored. Nectar feeding has been observed in parasitic flies in the families Tachinidae and Bombyliidae (Jervis et. al. 1993). Pollen and nectar also may serve as a secondary food resource for predatory mites. Leius (1967) reported a study to compare parasitism rates of codling moth and tent caterpillar in orchards with varied amounts of wild flowering plants in the orchard floor. Five times as many parasitized codling moths were found in orchards with rich floral undergrowth than in florally impoverished orchards. The same study found four times as many tent caterpillars parasitized in the florally diverse orchards.

Habitat Manipulation for Enhanced Hover fly Activity

An association between wild flowering plants and increased numbers of hover flies has been repeatedly observed. Cowgill et al. (1993) found greater abundance of hover fly adults in headlands without herbicide treatments where the natural fauna was allowed to grow than in headlands treated with herbicides. They also documented a higher hover fly egg: aphid ratio on the weeds in the untreated headlands. In a similar study, Ruppert and Molthan (1991) observed hover flies in a variety of field boundaries which were rated for their floral density and found a positive correlation between availability of flowers and numbers of adult hover flies.

The association between florally rich wild fauna and greater hover fly populations has aided in the widespread adoption of a program in England called the Headlands Conservation Program. This program provides field management guidelines which promote the growth of broadleaf weeds and associated arthropod populations in field margins and field headlands by not spraying insecticides in these areas and either not spraying herbicides or using grass selective herbicides (Boatman 1989). The primary goal of this program is to preserve gamebird chicks which rely on arthropods for food, however, the potential for enhanced biocontrol of crop pests by encouraging natural enemies has been an added recognized benefit (Cowgill 1989). Selective weed control programs have been designed to promote growth of particular wild flowers which are "preferred" by hover flies (Cowgill et al. 1993).

Recognition of the benefits of conserving wild flowering plants in agroecosystems led to efforts to augment wild flower populations by planting flowering plants near farm fields. Harwood et al. (1992) drilled field margins with native British wildflowers and found significantly higher numbers of adult hover flies than in field margins without herbicide treatment where natural vegetation was allowed to regenerate, thus demonstrating the added benefit of augmenting natural "weedy" vegetation with intentional floral plantings.

Research on providing floral resources has intensified in the past decade. Several studies have been conducted to evaluate enhanced biological control of aphids by the attraction of hover flies to flowering plants in and around farm fields (Harwood et al. 1992, Holland et al. 1994, White et al. 1995, Hickman et al. 1996). Evidence to document enhanced biological control has been sought in three main forms: 1) increased numbers of hover flies in the farm fields with floral resources, 2) increased oviposition rates in the treatment fields, and 3) decreased aphid numbers in the treatment fields. Results have been inconsistent from year to year and field to field. The following discussions of these studies present some possible explanations for incongruous results.

Field margins in the United Kingdom.

In the United Kingdom the cereal aphid, *Sitobion avenae*, is a pest which can cause economic damage in cereal crops. In 1992 and 1993 Hickman and Wratten (1996) drilled field boundaries of winter wheat with *Phacelia tanacetifolia* to attract hover flies and enhance biological control of aphids. In 1992, more hover flies were caught in traps at every distance into the experimental field than in the control fields. However oviposition rates and aphid numbers did not differ. It was noted that the wheat matured early this year resulting in early aphid colonization at a time before Hover fly oviposition had resulted in egg laying and therefore a lack of aphid control may have resulted. The following year, 1993, numbers of hover fly adults were not statistically different between fields, however numbers were consistently higher in fields with *P. tanacetifolia* borders than in control fields. Significantly higher numbers of hover fly eggs were found in *P. tanacetifolia* fields. Aphid numbers were not statistically different early in the season, but significantly different from the third week of sampling on. It was noted that the timing of lower aphid numbers in the *P. tanacetifolia* fields coincided field observations of third instar larvae; which is the hover fly larval stage that feeds on the greatest numbers of aphids. The authors concluded that there is a critical window of time in which crop, aphid and predator phenologies coincide resulting in adequate oviposition rates to enhance aphid control. This timing apparently occurred in 1993, but did not occur in 1992. The authors noted that this fact does not deter from the value of this type of field margin management when one considers the ease of implementation and low economic cost.

Field margins in New Zealand.

A similar study was conducted in New Zealand in 1994 in a cabbage field to asses the potential of attracting hover flies with flowers leading to increased biocontrol of the cabbage aphid, *Brevicoryne brassicae* (White et al., 1995). *Phacelia tanacetifolia* was drilled in the field margins of a commercial cabbage field. In this study significantly more hover flies were trapped in experimental fields than in control fields and aphid numbers were significantly lower in experimental fields. Significant differences in oviposition rates were not detected, however. The authors concluded that even though the high market value of broccoli and low tolerance for damage make complete elimination of pesticides unlikely, but the use of "soft" insecticides and beneficial insectary plants may form an integrated management strategy.

California interplanting studies.

In California, two studies have been conducted to investigate the potential of interplanting floral strips in farm fields as in field insectaries to enhance biological control. Kloen and Altieri (1990) interplanted mustard in a broccoli field to attract hover flies and enhance aphid control of the cabbage aphid, *Brevicoryne brassicae*. Their hypothesis was that the interplanting would result in reduced aphid numbers, but they also investigated the competition between the crop and flowering plant. Sowing dates of the mustard were varied to determine the critical period of competition. It was found that delaying sowing dates of the mustard to one week after broccoli transplanting did not result in significant broccoli yield loss. In this study, no significant differences between treatments were found for hover fly larvae, hover fly eggs, or aphid numbers. The plot size however was extremely small (2 by 2 m.), which may have been too small a scale to detect treatment effects.

In Salinas, Ca. a similar study was conducted in 1992 Chaney and reported by Grossman and Quarles (1993). Alyssum (*Lobularium maritima*) was interplanted in a lettuce field for aphid control. Chaney selected alyssum because it is quick to establish, attractive to hover flies, uncompetitive with the crop, and easy to cultivate out, making it an unlikely weed problem (Grossman and Quarles, 1993). Unfortunately the study was abandoned because alyssum appeared to attract leaf miners, a pest of concern in lettuce (Chaney, personal communication).

Insectary Plantings: Additional Considerations

Much research is needed to identify which plants have the greatest potential as beneficial insectary plants. Aside from floral attractiveness a number of other factors must be considered. An understanding of the phenology of the target pest is crucial and whether the critical period of control synchronizes with the blooming time and phenology of the natural enemy (Bowie et al. 1995, Hickman and Wratten 1996). Successful integration of a beneficial insectary planting into a particular farming system also requires an understanding of how it will fit into the overall management scheme of that system. Different plants may be better suited to different farming systems. Various approaches might include strip intercropping, in - field interplanting, perennial, low maintenance borders, annually - drilled field margins, and perennial and annual cover cropping. The appropriateness of each strategy will depend on parameters of the particular system of interest. For example, a fast growing annual would be desirable for an annual row cropping system, but a low growing perennial, which may serve as a permanent ground cover, might be more desirable in an orchard system.

Agronomic considerations also must be taken into consideration in designing an insectary planting. Drilling in the field margin may be more manageable agronomically than within field, especially if drilling times of the flowers differed from drilling of the crop (Hickman and Wratten 1996). Field margin plantings may prevent dispersal of potential weed seed from the flowers into the field and would also avoid any potential problems involved with harvesting the crop. Additionally, if the grower decided to spray the crop it would be easier to accomplish without spraying the field margins, potentially avoiding pesticide application to this beneficial arthropod reservoir.

Clearly economic costs of establishing and maintaining insectary plantings must be considered. Field area taken out of production may result in decreased crop production. Within field plantings also may compete with crop plants for nutrients, water, and sunlight, thus effecting productivity (Kloen and Altieri 1990). Planting in the field margins may have less impact since this area is generally left unplanted or herbicide treated. In addition, by separating out the flowers and crop plants, in margins or strips, nutrients could be amended selectively and competition could be avoided. Another approach to minimizing economic loss is planting an economically viable insectary crop. Ideas suggested, which warrant further investigation, include growing flowers for the cut or dried flower market and growing flowering plants for seed production.

Field Placement of Flowers

One key question emerging from studies is how far from the floral resource will natural enemies disperse into the crop field. Optimal spacing would be a balance between attracting adequate numbers of hover flies and minimizing time, energy, and resource inputs in plant establishment.

It is unknown whether natural enemies are more attracted to concentrated floral resources or dispersed resources. The majority of studies have utilized concentrated resources, in part due to management considerations, which placed flowering strips within the field (Loveii et al. 1993, Loveii et al. 1992) or in the field margins (Hickman and Wratten, 1996, White et al. 1994, Holland and Thomas 1994). Altieri (1992) interplanted flowering plants, which dispersed the floral resource throughout the field. Researchers conducting studies with concentrated floral resources have observed varied rates of oviposition throughout the field. Dispersion and subsequent oviposition rates tend to peak at some distance from the flowers and then decrease with increasing distance from the flowering strip. Dispersal distances of adult hover flies were found up to 250 m from *P. tanacetifolia* strips in the study by Hickman and Wratten 1996. However this study also found the greatest numbers of Hover fly eggs within one meter from the flowering margin. In the New Zealand study by White et al. (1995) the strips of *P. tanacetifolia* were only 22.5 m apart, however, the majority of adult hover flies were caught within 0.5 m from the flowers. Loveii et al. (1992) monitored hover fly dispersal from a flowering strip in a wheat field and estimated that hover flies would disperse at least 15 m into the crop on either side of the strip. These authors suggested that 30 m spacing between strips would be an adequate distance. Clearly such equivocality in results suggests that dispersal will be species and site specific and further research is needed to determine what parameters in the system are affecting dispersal rates. Information about agronomic aspects of flowering plants, hover fly behavior (see section on hover fly oviposition), aphid behavior may lend insight into optimizing floral placement.

Considerations of the greater environmental setting in which the field is located may be useful in designing an insectary planting. Loveii et al. (1992) noted that greater numbers of hover flies were caught in traps on the windward side of flowering strips and suggested that a planting may be most beneficial on the downwind side of a field because hover flies might be more apt to disperse upwind and into the field. Further research is needed to assess this effect.

It is still unknown how much of a population increase is necessary to accomplish adequate aphid control. We feel that due to the diminishing hover fly numbers with increasing distance from the floral resource that we may achieve greater effectiveness on a large scale by dispersing the flowering plants throughout the field interplanted along with the crop plants. Placement of flowering plants in the field may be advantageous over field margins because dispersal into the field can occur in all directions, thus possibly increasing the crop area benefiting from hover fly activity.

Hover fly Biology

General descriptions of all life stages of hover flies are presented by Stubbs and Falk (1983) and Chambers (1988). Hover flies are in the order Diptera and distinguished from other Diptera by the presence of a "false vein" in the wings. They are yellow and black flies, often striped, however, some species are all black (Stubbs and Falk 1983). They are highly mobile insects which spend a great deal of their adult lifetime foraging for pollen and nectar, and exhibit a characteristic hovering behavior, where they suspend themselves in flight (Wirth et al., 1965). Many species are aphidophagous in the larval life - stages, making them an important group of entomophagous insects. Most aphidophagous species are in the tribes Syrphini and Melanostomini (subfamily: Syrphinae) (Stubbs and Falk 1983).

No extensive taxonomic surveys of hover flies have been conducted in Oregon. There are, however, reportedly both holarctic and palearctic species and general taxonomic descriptions are available for Canada (Vockeroth 19), North America (Cole 1969) and Europe (Stubbs and Falk 1983). Interestingly, species found on the west coast of the United States are reported to be more closely related to European species than to species found in the eastern United States (Cole 1969). Many species are highly variable which can be a problem in descriptions of classifications (Stubbs and Falk 1983).

Phenology.

The phenology of hover flies is diverse and varies among species. Life cycles of hover flies can be univoltine or multivoltine with diapause occurring in the larval, pupal, or adult stages (Chambers 1988). Some species exhibit migratory behavior (Schneider 1958, Johnson 1960). Surveys of hover flies show seasonal variability in abundance and diversity of species present (Banks 1959, Dean 1958, Hagvar 1983). Surveys of species in England show most species have a slight peak in abundance in early spring, but reach maximum numbers in late summer (August) (Banks 1959, Dean 1958, Hagvar 1983). Hagvar suggested that increased catches of hover flies in August could be due to decreasing availability of flowering vegetation drawing greater numbers to flowering plants still in bloom.

Gilbert (1985) conducted an extensive study of adult hover fly activity. He found that hover flies exhibit diurnal activity patterns which vary from species to species. Of the 17 species surveyed, peak daily activity occurred mid morning, quickly declining after noon. Hover flies generally spend most of their time feeding, with resting periods between feeding visits (Gilbert 1985). Larger species, measured by thorax width, were observed to become active at lower temperatures, and to spend less time in flight than smaller species. The exception is the smaller species, *Metasyrphus scalare*, which becomes active at lower temperatures. This species feeds on anemophilous pollen and such activity was proposed to be fueled by the proline content of this pollen type (Gilbert 1985).

Oviposition of Adult Hover Flies.

Olfactory cues from aphid honeydew have been shown to stimulate egg laying behavior in many species of syrphids (Dixon 1959, Budenberg and Powell 1992). Chandler (1968) investigated oviposition of hover flies and observed behavioral differences which categorize them into two groups. The first is termed aphidozetic, in which oviposition is stimulated by the presence of aphids. Hover flies in the genus *Syrphus* were observed to lay single eggs close to aphids. The second group is termed phytozetic, in which oviposition tends to be on plants uninfested with aphids. Species in the *Melanostoma* and *Platycheirus* genus were observed to lay eggs in batches on plants away from aphids. In a subsequent study Chandler (1968) investigated the role of leaf texture on oviposition. He compared oviposition rates on two cultivars of brussels sprouts, one with glossy leaves and one with waxy leaves. Certain hover fly species, which tended to be phytozetic species, demonstrated preferential ovipositing on one or the other type of leaf. Aphidozetic species showed much less differentiation between leaf textures. Chandler hypothesized that, in evolutionary terms, phytozetic hover flies are older than aphidozetic species. He reasoned that aphidozetic species evolved an obligatory aphidophagous feeding regime which necessitated discriminatory ovipositional behavior of gravid females in response to aphid stimuli. This discriminatory ability has been observed to diminish with age. Older aphidozetic gravid females tend to lay eggs further from aphid groups than young gravid females (Chandler 1968).

Many hover fly species exhibit an aphid density dependent oviposition response (Dixon 1959, Chandler 1968). The number of aphids at which the highest number of eggs are laid varies from species to species, but there is a positive correlation for each species investigated. This behavior was suggested by Chandler to decrease intraspecific competition. At extremely high aphid densities however oviposition was observed to be inhibited (Chandler 1968).

In a study spanning three years, Dixon (1959) observed that the highest numbers of hover fly eggs laid prior to the peak number of aphids which resulted in synchronization between maximum numbers of hover fly larvae and maximum numbers of aphids present. This synchronization has important implications in the role of hover flies as regulators of aphid populations.

Of the insectary field trials reviewed (see section on habitat manipulation for enhanced hover fly activity) higher oviposition rates are not generally observed at higher rates in floral plots than in control plots. The exception is one year of Hickman and Wratten (1996). However in these same trials other evidence of enhanced biocontrol has been presented, including lower aphid populations. This presents the point that oviposition rates are not a good indicator of aphid control (Harwood et al. 1994) since higher aphid numbers in control plots may stimulate higher rates of oviposition (Chandler, 1968).

Hover fly Larvae.

Hover fly larvae are maggots, with a tail-like feature which contains spiracles used for breathing. They pass through three larval instars during development and are 1 - 2 cm long when fully grown. Although taxonomic keys to the larvae of some species exist (Dixon 1960) the best way to identify them is to rear them to adults (Gilbert 1986).

The larvae of many hover fly species are voracious aphid feeders. Their voracity of has been demonstrated to be dependent on aphid density (Dixon 1958). Many species of larvae are active, mobile predators. The third instar feeds on the highest number of aphids. Larvae are often nocturnal and feed 3 to 10 times as frequently at night than during the day (Ankersmit et. al., 1986). They are reported to hide during the day at the base of plants, in curled leaves, or in nooks and crannies of plants (Gilbert, 1986). Species of interest as natural enemies feed on aphids, but there are also species that feed on rotting materials and dung (e.g. *Eristalis tenax*).

Developmental periods of hover fly eggs, larvae, and pupae were investigated by Ankersmit et al. (1986). They demonstrated that developmental periods are temperature dependent and become shorter at higher temperatures. At 15° C development *Episyrphus balteatus* from egg to adult took an average of 40 days and no eggs were laid. At 20° C development was completed and oviposition began in an average of 8 days.

Not only do higher aphid densities result in greater numbers of hover fly larvae (see section on oviposition), but larval and pupal weights increase with increasing prey availability (Dixon 1959). Due to the functional response of syprhids to prey density increases, at higher prey densities lower predator:prey ratios are required to prevent continued prey growth (Tenhemberg 1995).

Biocontrol potential

In a review of the aphid control potential of aphidophagous insects, van Emden (1966) identified three main factors influencing the effectiveness of aphid biocontrol; 1) voracity of the predator species, 2) synchronization of the predator species with the critical period of pest control and 3) the rate of reproduction of the aphid species. Each of these factors may differ from season to season and species to species, making prediction of biocontrol potentials difficult. Poor synchronization between predator and prey species has been cited as a barrier to effective biological control of hover fly in several instances (Dixon 1959, Hickman and Wratten 1996).

Estimates of the predatory potentials of hover fly larvae have been conducted in laboratory experiments, field cages and with the use of models. The potential of aphid feeding hover fly larvae to limit aphid population growth has been documented quantitatively by Chambers and Adams (1986). Their study involved a mathematical model to compare observed feeding rates of hover fly larvae in the laboratory with observed declines of aphid populations in the field. Mathematical models based on laboratory data may not, however, be accurately extrapolated to field feeding capacities as field conditions and feeding efficiency are variable (Tenhemberg 1995).

Field studies have also been used to estimate predatory feeding capacities. Tenhumberg (1995) developed a model based on predatory rates of in field cages and estimated the predatory potential of *Episyrphus balteatus* to be up to 396 aphids during larval development. Dixon (1959) estimated with a mathematical model, based on field studies of *E. balteatus* predation efficiency, that a ratio as high as 1:245 resulted in nearly complete elimination of cereal aphid populations.

Horticultural aspects of flowering plants

Phacelia tanacetifolia.

Phacelia tanacetifolia, an annual species in the family Hyrophyllacea, is a California native wildflower which has been used as a horticultural ornamental, a pollen plant for bees, a covercrop, and a beneficial insectary plant by researchers (Lovei 1992, Lovei et al. 1993, White et al. 1995, Hickman et al. 1996).

In addition to attractiveness to hover flies, agronomic characteristics of *P. tanacetifolia* have been cited as reasons for its use as a beneficial insectary plant. It will grow on most soils, can be direct seeded, is frost tolerant to -8° C and has a long flowering period of at least six weeks from a single drilling (Hickman and Wratten 1996).

In a study by Bowie et al. (1995) *P. tanacetifolia* was sown each month for 12 consecutive months and grew to flower from each planting date, again demonstrating its overwintering potential. In this study, conducted in N.Z., the earliest blooming date from overwintering was October. October in the southern hemisphere is equivalent to April in Oregon.

A few disadvantages of *P. tanacetifolia* should be considered. There are reports of its potential to become a weed seed; probably due to prolific seed production (Stevens 1989). Recommendations for agronomic production include the use of Treflan (Trifluralin) for weed control, suggesting it is tolerant to this herbicide, which is also widely used as an herbicide in broccoli production in the Willamette Valley. *P. tanacetifolia* has also been reported to be highly susceptible to MCPA, Gesagard, Gardoprim, and Glean (Stevenson 1989). Another disadvantage discussed by researchers is reports that the short tongues of hover flies cannot access the nectar from *P. tanacetifolia* due to the flowers' deep corolla (e.g. Bowie et al. 1995). The potential for hover flies to alternatively utilize aphid honeydew as an energy source has been argued against this fact ruling out its use as an insectary plant (White et al. 1995, Hickman et al. 1996).

Coriandrum sativa.

Coriandrum sativa is a flowering plant in the family Apiaceae. Commonly it is known as Cilantro when used as an herb and Coriander when used as a culinary seed. Flowers grow in an umbel - like arrangement. Gardeners know of cilantro's' tendency to bolt to flower as spring temperatures warm up, a characteristic making it a potentially useful insectary plant as early blooming may be achieved.

Coriandrum sativa has been demonstrated to be attractive to hover flies. Field trials in New Zealand and the United Kingdom found that it was fed from preferentially over *P. tanacetifolia* (MacLeod 1992, Lovei et al. 1993). Flowers in the Apiaceae family have also been reported as attractive to parasitic hymenoptera (Jervis and Kidd 1986).

Sowing to flowering times were shown to differ between different cultivars of *C. sativa* in a study by Bowie et al. 1995. In this study, in New Zealand, it was sown once a month for 12 months and was observed to flower as early as September (March in Oregon).

Lobularia maritima.

Lobularia maritima is a member of the family Brassicaceae and commonly known as sweet alyssum or carpet of snow. California extension agent Bill Cheney used *L. maritima* as an insectary plant due to a number of desirable qualities (see section on habitat manipulation for enhanced Hover fly activity). Plants are about 6 in. to 12in. tall. Blooming can be achieve as short as 6 weeks from seeding and will continue until fall. A characteristic sprawling growth pattern creates a ground covering effect which suppresses weed growth.

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Chapter 2

The Relative Attractiveness of Potential Beneficial Insectary Plants to Hover Flies (Diptera: Syrphidae) and Parasitic Wasps (Hymenoptera: Ichneumonidae and Brachonidae)

Abstract

Establishing flowering plants in and around farm fields to provide pollen- and nectar resources for natural enemies has shown promise as a strategy to enhance biological control of crop pests. Natural enemies are selective in their feeding, however, and show preferences for certain plant species. In this study the relative attractiveness of 11 flowering plants to aphidophagous hover flies (Diptera: Syrphidae) and parasitic wasps (Hymenoptera: Ichneumonidae and Brachonidae) was evaluated at the Oregon State University Vegetable Research Farm. Six of these plants also were evaluated for attractiveness to aphidophagous hover flies at two on-farm sites. Of the 16 species of hover flies collected, the six most common species collected at all three sites were: *Meliscaeva cinctella, Toxomerus marginatus, T. occidentalis, Sphaerophoria sulphuripes, S. pyrrhina,* and *Scaeva pyrastri.* Attractiveness of flowering plants to hover flies was assessed by conducting timed observations of feeding-visit frequencies. Parasitic brachonid and ichneumonid wasp abundance was estimated by timed vacuum sampling. Blooming times of plant species varied, and evaluations were made only during blooming periods.

Attractiveness differed by dates and sites. Among early-season flowering species, cilantro (*Coriandrum sativa*) was the most attractive to hover flies and mustard (*Brassica juncea*), buckwheat (*Fagopyrum esceulentum*), and Korean licorice mint (*Agastache rugosa*) were most attractive to parasitic Hymenoptera. Among late-season flowers, yarrow (*Achillea millefolium*), fennel (*Foeniculum vulgar)*, and Korean licorice mint (*Agastache rugosa*) were most attractive to hover flies, but attractiveness to

parasitic wasps did not differ. Selection of flowering plants for augmenting natural enemies requires considering flowering phenologies and timing of natural enemy and pest phenologies.

Key Words: insectary plants, Syrphidae, habitat manipulation, natural enemies, biological control, parasitic Hymenoptera, Brachonidae, Ichneumonidae

Introduction

Beneficial insectary planting refers to intentionally introducing flowering plants into agricultural ecosystems to increase nectar and pollen resources required by some natural enemies of insect pests. Several species of natural enemies, including aphidophagous hover flies and parasitic Hymenoptera, depend on pollen and nectar for reproductive success and longevity (Schneider 1948, Jervais 1986). Surveys of weed and wild-plant compositions in agroecosystems have associated florally abundant, non-crop habitat with significantly higher numbers of pollen-and nectar-feeding natural enemies in and around farm fields (Cowgill 1989, Cowgill et al. 1993a) and orchards (Leius 1967). Modern agricultural practices, such as tillage and herbicide use, create farmscapes with limited diversity of flowering insectary plants which may limit the potential role of naturally-occurring predators and parasitoids in biological control. Several studies have demonstrated the potential for establishing flowering plants in or around farm fields to attract natural enemies and enhance biological control of crop pests in adjacent fields (Kloen and Altieri 1990, Harwood et al. 1992, Harwood et al. 1994, Holland et al. 1994, White et al. 1995, Hickman and Wratten, 1996).

Research is still needed to identify which plants have the greatest potential as beneficial insectary plants. An understanding of the seasonal phenology of the target pest is crucial and whether the critical period of control synchronizes with the blooming time of the insectary flower and the phenology of the natural enemy species. Adult hover flies and parasitic wasps exhibit a high degree of selectivity in the flowers from which they feed (Leius 1960, Cowgill et al. 1993b, Lovei et al. 1993, Lunau and Wacht 1994). Many flowering plants are reputed to be insectary plants, but most of this information is anecdotally based.

The objectives of this study were: (1) to identify aphidophagous hover fly fauna present in Oregon agricultural fields, (2) to evaluate the relative attractiveness of selected flowering plants to adult hover flies and to parasitic Hymenoptera.

Materials and Methods

Three field studies were conducted in 1997, one at Oregon State University (OSU) Vegetable Research Farm near Corvallis, OR, and two at local organic farms (Persephone Farm, near Lebanon and Denison Farm, near Corvallis). At the OSU site, 11 flowering plants were grown in 1.5 m^2 plots in a complete randomized-block design with four replications. Flowers included seven annuals: annual alyssum (*Lobulariamaritima*), calendula (*Calendula officinalis*), cilantro (*Coriandrum sativa*), mustard (Brassica juncea), phacelia (*Phaceliatanacetifolia*), buckwheat (*Fagopyrum esceulentum*), and marigold (*Tagetespatula*), and four perennials: yarrow (*Achillea millefolium*), Korean licorice mint (*Agastache rugosa*), fennel (*Foeniculum vulgare*), and aurinia, or perennial alyssum (*Aurinia saxitalis*).

Calendula, cilantro, yarrow, Korean licorice mint, and fennel were started from seed in the greenhouse on 25 March 1997 and transplanted in the field on 20 May. Calendula, cilantro, marigold, yarrow, Korean licorice mint, fennel, and aurinia each had sixteen plants per plot. Phacelia, mustard, and buckwheat were direct seeded on 20 May. Direct seeded plants were thinned to 10 to 15 cm spacing between plants two to three weeks after planting. Alyssum and aurinia were purchased from a local nursery. Alyssum plants were six weeks old at the time of planting. Alyssum had 36 clumps per plot, clumps were comprised of an average of 8 to 10 plants per clump.

Aurinia plants, which do not produce bloom in the first year, were purchased as one-year-old plants.

At the two organic farm sites, six flower species were grown in 1 m^2 plots in a complete randomized-block design with three replications. Flower species included three annuals: alyssum, phacelia, and cilantro, and three perennials: yarrow, agastache, and fennel. All plants were started in the greenhouse on 24 March, except for alyssum, and planted on 19 May. Alyssum was purchased from a local nursery as six-week-old seedlings and planted on 19 May.

Survey of Hover Fly Species.

Hover fly species feeding from test flowers were surveyed from early May through late September. Adult hover flies were captured with a sweep-net at all three locations. Representative specimens were identified to species by Christian Kassebeer, University of Kiel, Germany and subsequent identifications of all aphidophagous species were identified from reference specimens and with keys by Vockeroth (1992).

Hover Fly Observations.

Timed observations of hover fly visits to flowers were made from 7 July to 2 Sept. at the OSU site; 14 July to 2 Sept. at Denison farm; and 16 July to 5 Sept. at Persephone farm. Relative attractiveness was assessed by observing the frequency of feeding visits to each plot per 2 min. Weekly observations were made, on each plot of flowers in bloom, between 10:00 am and 12:00 am because this is the time of peak daily activity of hover flies as observed in the United Kingdom by Gilbert (1985). In this study, a plant was considered to be in bloom when >50% of its flowers were open.

Parasitoid sampling.

Densities of adult parasitoids (Ichneumonidae and Brachonidae) were estimated on flowering plants from 10 July to 4 Sept. One m^2 samples were taken weekly within each flower block with a vacuum sampler. The sampler is a modified leaf-blower with a reversed motor to create suction, which has increasingly become an alternative to the previously standard "D-vac" for quantitative insect sampling (Wright and Stewart 1992, Wilson et al. 1993, Macleod et al. 1994). A fine mesh screen, small enough to capture parasitic Hymenoptera, was installed in the 15 cm-dia vacuum tube extension to catch vacuumed insects. Sampling area was defined by dropping a 1 m^2 metal over the flowers. The cylinder has an extension of flexible heating duct attached to allow variable sampling height. One person dropped the metal cylinder over the flowers and held the duct pipe approximately 0.5 m above the flowers while a second person inserted the suction tube of the vacuum sampler for a 1 min timed sample. During sampling, the suction tube was focused at the height of the flowers. Insect samples were emptied into a plastic bag, aspirated into a vial, placed in a cooler on ice, and stored in a freezer until identified.

Statistical Analysis.

Analysis of variance procedures and mean separation tests were conducted using the Statistical Analysis Software (SAS, 1996). A Duncan's multiple range test was used for comparing among means. Data were transformed by square root + 0.5 before analysis to improve the homogeneity of variances. An alpha level of 0.05 was used as a rejection criteria for hypothesis testing.

Results

A total of 160 hover flies, including 95 flies in 12 aphidophagous species, were caught in sweep nets at the three experimental sites throughout the season (Table 2.1).

Five species were caught at all three locations: *Meliscaeva cinctella, Sphaerophoria sulphuripes*, *Syrphus opinator*, *Toxomerus marginatus*, and *T. occidentalis*. *Allograpta micrura*, *Eupoedes fumipennis*, and *Melanostoma mellinum* were only found at Persephone Farm and *Paragus variables* and *Parasyrphus insolitus* were only found at Dennison Farm. Vegetation surrounding the two on-farm sites was diverse compared to the OSU site and may have influenced the greater number of species caught at these two locations. The geographical location of the three sites also varied which may have influenced the species present at each site. Persephone farm was on the eastern side of the Willamette Valley in the foothills of the Cascade Mountains. Both Denison Farm and the OSU Vegetable Research Farm were located near the Willamette River on the western side of the Willamette Valley.

Table 2.1. Hover fly species present at experimental sites and associated flower hosts in 1997.

Hover fly species	Location[a]	Flower host[b]
Allograpta micrura	P	cl
Eupoedes fumipennis	P	fn
E. lapponicus	P O	ag ph
Melanostoma mellinum	P	cl
Meliscaeva cinctella	P D O	bk fn yr
Paragus variables	D	yr
Parasyrphus insolitus	D	ag
Scaeva pyrastri	P D	ph
Sphaerophoria sulphuripes	P D O	al au ca cl mu yr
S. opinator	P D O	fn ph yr
Toxomerus marginatus	P D O	al cl ph
T. occidentalis	P D O	ag al cl fn yr

[a] P = Persephone farm; D = Denison Farm; O = OSU Vegetable Research Farm.
[b] al = alyssum; ag = agastache; au = aurinia; ca = calendula; cl = cilantro; fn = fennel; mu = mustard; ph = phacelia; yr = yarrow.

Hover flies observed on flowering plants were selective in their feeding. The mean number of hover flies (± SEM) observed feeding from flowering plants at the

OSU site is summarized in Table 2.2, at Persephone Farm in Table 2.3, and at Denison Farm in Table 2.4. Blooming periods differed among plant species at each site (Tables 2.2, 2.3, 2.4).

On certain dates certain plants were in bloom, but no hover flies were observed feeding from them. Clearly these plants were not attractive on those dates. These plants were dropped from the analysis to improve the homogeneity of variances between the attractive species present. Analysis were then conducted on all plants which had at least one hover fly observed to assess the relative attractiveness of these species.

OSU Vegetable Research Farm.

At the OSU site, 176 hover flies were counted in 288 min of observations from 7 June through 2 Sept. Hover flies visited every evaluated plant species except for agastache (Table 2.2). Overall, certain plants were poor attractors of hover flies including: marigold, agastache, fennel and yarrow. Aurinia and calendula were somewhat attractive and were generally fed from more frequently than the poorly attractive species but less than the more preferred species.

Cilantro, alyssum and buckwheat all were particularly attractive species. On the first sampling date alyssum was more attractive than all other species in bloom except for buckwheat, and buckwheat was more attractive than calendula, mustard, or aurinia. Cilantro was a particularly attractive species and was fed from preferentially on 24 July over all other plants in bloom and on 30 July over all other plants but alyssum. Phacelia was only in bloom on one sampling date. An evaluation of its attractiveness is difficult because, although it was visited by hover flies, the only other species in bloom were three of the poorly attractive species. On the last three sampling dates, few hover flies were present, feeding frequencies were low, and attractiveness did not differ among evaluated plants (Table 2.2).

Table 2.2. Mean number of adult aphidophagous hover flies (± SEM) observed visiting flowering plants per 2 min at Oregon State University Vegetable Research Farm in 1997.

	Date							
Flower	7 June	14 July	24 July	30 July	13 Aug	21 Aug	29 Aug	2 Sept
Alyssum	3.75±0.95a[a]	3.00± 1.08ab	1.25±0.95b	1.00± 0.41ab	-	-	-	-
Buckwheat	3.25±1.11a	3.00± 1.00ab	-	-	-	-	-	-
Calendula	0.75±0.48b	2.25± 0.75ab	0.00±0.00[c]	-	-	-	-	-
Cilantro	-[b]	4.00±1.08a	5.25±0.95a	2.00±0.58a	-	-	-	-
Marigold	-	-	0.50±0.50b	0.25±0.25b	0.00±0.00	0.00±0.00	-	-
Mustard	1.00±0.71b	4.00±0.71a	-	-	-	-	-	-
Phacelia	-	-	-	-	1.50±0.65	-	-	-
Agastache	-	-	-	0.00±0.00	0.00±0.0	0.00±0.00	0.00±0.00	0.00±0.00
Aurinia	2.00±0.91ab	1.25±0.48b	0.75±0.48b	0.25±0.25b	-	-	-	-
Fennel	-	-	-	-	-	0.25±0.13	0.00±0.00	0.25±0.25
Yarrow	-	-	-	0.25±0.25b	0.33±0.48	0.25±0.25	0.50±0.18	0.25±0.25

[a]Means followed by different letters within a column are significantly different at $\alpha = 0.05$.
[b] Dashes indicate plant was not > 50% in bloom.
[c]Observations with 0.00 mean and 0.00 SEM are not included in analysis.

Persephone Farm.

At Persephone Farm, 153 hover flies were observed in 144 min from 16 July through 5 Sept (Table 2.3). Cilantro was highly attractive, as it was at the OSU site, and was fed from at least 6 times as frequently as other plants in bloom on 16 July and 25 July. Alyssum was observed only on 16 July because it was attacked by flea beetles following the harvest of nearby broccoli and did not have enough flowers left to be evaluated. After 1 Aug, cilantro stopped blooming and no significant differences in feeding preferences among the other flowering plants were observed. As at the OSU site, neither agastache or yarrow were very attractive. However, on ll Aug, fennel, which was not attractive at OSU or Denison farm, became the preferred flower and on 5 Sept it attracted 8.33 hover flies in the 2 min of observations.

Table 2.3. Mean number of adult aphidophagous hover flies (± SEM) observed visiting flowering plants per 2 min at Persephone Farm in 1997.

	Date					
Flowers	16 July	25 July	1 Aug	11 Aug	18 Aug	5 Sept
Alyssum	1.00 ± 1.00b[a]	-	-	-	-	-
Cilantro	6.00 ± 2.08a	13.00 ± 3.61a	1.00 ± 0.58	-	-	-
Phacelia	1.00 ± 1.00b	2.00 ± 1.00b	0.67 ± 0.33	0.33 ± 0.33b	-	-
Agastache	0.33 ± 0.33b	2.00 ± 0.00b	0.33 ± 0.33	1.67 ± 0.66ab	0.00 ± 0.00	3.67 ± 1.20ab
Fennel	-[b]	1.00 ± 0.58b	1.67 ± 1.20	3.33 ± 0.33a	0.33 ± 0.33	8.33 ± 0.67a
Yarrow	-	1.33 ± 0.88b	0.00 ± 0.00[c]	0.67 ± 0.67b	0.67 ± 0.67	0.67 ± 0.67b

[a]Means followed by a different letter within a column are significantly different at $\alpha = 0.05$.
[b]Dashes indicate plant was not > 50% in bloom.
[c]Observations with 0.00 mean and 0.00 SEM are not included in analysis.

Denison Farm.

Flowers were in bloom and observations of 133 hover flies were observed in 180 min at Denison Farm from 14 July through 2 Sept (Table 2.4). As at the OSU site, agastache, fennel and yarrow were not very attractive to hover flies. Although no significant differences in feeding frequencies were observed on the first date, 14 July, cilantro was preferred on 24 July, attracting 9 hover fly adults during the 2 min of observations, and was again attractive on 30 July. After 30 July, cilantro stopped blooming and, on 6 Aug, hover fly numbers were low and no significant differences were found among flowers. On 12 Aug, however, phacelia was the preferred flower and was fed from at least 6 times as often as the other flowers in bloom (Table 2.4).

Table 2.4. Mean number of adult aphidophagous hover flies (± SEM) observed visiting flowering plants per 2 min at Denison Farm in 1997.

	Date							
Flower	14 July	24 July	30 July	6 Aug	12 Aug	19 Aug	29 Aug	2 Sept
Alyssum	1.00 ± 0.58	3.67 ± 1.20ab[a]	1.33 ± 0.66ab	-	-	-	-	-
Cilantro	1.00 ± 1.00	9.00 ± 1.15a	2.67 ± 0.88a	-	-	-	-	-
Phacelia	-[b]	-	-	0.33 ± 0.33	8.67 ± 2.40a	2.00 ± 1.00	1.33 ± 0.33a	4.00 ± 1.53
Agastache	0.33 ± 0.33	1.33 ± 0.88b	0.67 ± 0.33ab	0.33 ± 0.33	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.33b	0.67 ± 0.33
Fennel	-	-	0.00 ± 0.00[c]	0.00 ± 0.00	0.00 ± 0.00	0.67 ± 0.33	-	-
Yarrow	-	1.33 ± 1.33b	0.00 ± 0.00	0.67 ± 0.6	1.67 ± 1.20	0.67 ± 0.67	0.67 ± 0.33ab	0.00 ± 0.00

[a]Means followed by different letters within a column are significantly different at $\alpha = 0.05$.
[b]Dashes indicate plants were not > 50% in bloom.
[c]Observations with 0.00 mean and 0.00 SEM are not included in analysis.

Parasitic Hymenoptera at OSU Vegetable Research Farm.

On most sampling dates few differences were found between numbers of adult parasitic Hymenoptera caught on flowering plants (Table 2.5). On certain flowers few hymenoptera were caught on any date including: aurinia, yarrow and fennel. On the first sampling date more Hymenoptera were caught on mustard than on aurinia, but not more than on other plants in bloom. On 31 July more wasps were caught on agastache, but 7 July plants in bloom did not differ in the number of wasps caught. Numbers of Hymenoptera caught on plants in bloom did not differ on the last five sampling dates.

Table 2.5. Mean number parasitic Hymenoptera (Ichneumonidae and Brachonidae) (± SEM) caught per 1 min using a vacuum sampler in a contained 1 m^2 cylinder enclosing flowering plants at Oregon State University Vegetable Research Farm in 1997.

Flower	Date							
	10 July	18 July	31 July	7 Aug	14 Aug	22 Aug	29 Aug	4 Sept
Alyssum	0.25±0.25b[a]	0.50±0.29b	0.25±0.25b	0.50±0.50	-	-	-	-
Buckwheat	0.75±0.75b	3.00±1.01a	-	-	-	-	-	-
Calendula	1.00±0.71ab	1.25±0.25b	-	-	-	-	-	-
Cilantro	-[b]	1.00±0.71b	-	-	-	-	-	-
Marigold	-	-	0.50±0.29b	0.00±0.00	0.75±0.25a	-	-	-
Mustard	3.25±1.70a	1.25±0.25b	-	-	-	-	-	-
Phacelia	-	-	-	0.50±0.29	0.75±0.25a	-	-	-
Agastache	-	-	2.75±0.95a	0.00±0.00	0.25±0.25ab	0.25±1.03	0.50±0.50	0.25±0.25
Aurinia	0.00±0.00[c]	0.50±0.29b	0.25±0.25b	0.00±0.00	-	-	-	-
Fennel	-	-	-	-	-	-	0.25±0.25	0.25±0.25
Yarrow	-	-	-	0.00±0.00	0.00±0.00	0.00±0.00	0.25±0.25	0.00±0.00

[a]Means within a column followed by different letters are significantly different at $\alpha = 0.5$.
[b]Dashes indicate plant was not in bloom.
[c]Samples with 0.00 mean and 0.00 SEM are not included in analysis.

Discussion

In this study, as in previous reported studies, foraging hover flies exhibited a high degree of selectivity in their feeding. This selectivity, however, is related to the other floral resources available. In this study, one plant became the "most preferred" species when another highly attractive species stopped blooming, for example, the shift in preference from cilantro to fennel when cilantro stopped blooming at Persephone Farm (Table 2.3). In the absence of cilantro, whether fennel would have been fed upon at higher rates all along is unknown. We must consider, however, that although each flower species was fed upon to some degree, foraging hover flies are clearly attracted to some plants over others, which is likely due to a greater suitability of specific floral resources over others. Evidence from our study suggest that cilantro may have the greatest potential for attracting hover flies, however, alyssum, phacelia, buckwheat, mustard, and fennel were also significant providers of floral resources for hover flies. Calendula, marigold, aurinia, yarrow, and agastache appeared to be poor attracters of hover flies.

The blooming periods in this study were dependent on our planting dates and methods. Perennial plants were grown from seed and would likely have flowered earlier in the season had they emerged from over-wintering as a mature plant. Because insect feeding preferences may vary throughout the season, we must consider that the attractiveness of evaluated plants might have been different if evaluated during different periods of time.

Evidence was found that mustard, buckwheat and agastache were all attractive to parasitic wasps in July. By August, however, few parasitoids were collected in the sampling and there was little difference among flower treatments.

Our observations of attractiveness of both cilantro and fennel reinforce other reports of feeding from umbelliferous plants, which have short corollas (Gilbert 1981). In a similar study, Loveii et al. (1993) found cilantro was preferred over other available floral resources and noted that the open-blossom morphology of cilantro allowed feeding from both pollen and nectar. Phacelia, however, attracts hover flies that feed from its pollen (White et al. 1995, Hickman and Wratten 1996) although its deep corolla limits nectar availability.

Other studies have attributed attractiveness to color. Cowgill (1989) conducted surveys of wild flowering plants and noted that yellow and white flowers were particularly attractive . Lunau and Wacht (1994) demonstrated that feeding behavior is stimulated in the laboratory by yellow. In our study, cilantro, buckwheat, alyssum, and fennel, were all attractive plants that are white or yellow. Phacelia, however, which has blue flowers, also was particularly attractive at Denison Farm and was used by Hickman and Wratten (1996) to attract hover flies. Clearly, several factors can influence the attractiveness of a flowering plant to foraging hover flies.

Although attractiveness is likely a key factor in the effectiveness of beneficial insectary plants, other factors such as timing may be crucial. If pollen and nectar are not available when natural enemies need them, or not in time to attract them before the target pest species reaches its economic threshold, then the potential for enhancing biological control may not be realized. For an early-season crop, an early blooming flower, like alyssum or cilantro, might be preferable; likewise phacelia or fennel might be better suited for a late-season crop. The blooming periods in this study were dependent on our planting dates and methods. Research on the potential of manipulating blooming periods by adjusting planting dates or altering cultural methods (Bowie et al. 1995) may suggest management strategies for providing pollen and nectar during critical periods that synchronize with crop, pest, and natural enemy phenologies.

Another strategy is to choose several attractive plants with overlapping flowering periods to provide pollen and nectar over a longer time period. Additional considerations, before an insectary plant is selected, might include ease of crop harvest, competitiveness of the insectary plant with the crop, or the possibility of the insectary plants acting as a reservoir of pests or pathogens. Weed management strategies within the insectary plants must also be considered.

Clearly, costs of establishing and maintaining insectary plantings must be considered. Since limiting pest pressure with beneficial insectary plantings alone is unlikely, a cost comparison with pesticide use will probably not demonstrate an economic gain. However, used in conjunction with other integrated pest management tactics, such as selective insecticide use and planting resistant crop varieties, insectary plantings may play a role in tipping the predator prey ratio and enhancing biological control. An ability to avoid the use of broad spectrum pesticides and opt for "softer" pest suppression tactics may have additional benefits, such as, decreasing the development of pest resistance to insecticides, increasing the survival of other natural enemies in the system, reducing human exposure to pesticides, and the production of crops free of pesticide residue.

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Chapter 3

Interplanting of Alyssum (*Lobularia maritima*) or Cilantro (*Coriandrum sativa*) in Broccoli (*Brassica oleracea*) to Enhance Biological Control of Aphids by Hover fly Larvae (Diptera: Syrphidae) and Hymenopteran Parasitoids

Abstract

Hover fly larvae (Diptera: Syrphidae) are voracious aphid predators and have potential as biological control agents of economic importance. The Hymenopteran parasitoid *Diateriella rapae* is an important parasite of the cabbage aphid and green peach aphid in agricultural systems. Adult hover flies and parasitic wasps feed on pollen and nectar from flowering plants. Hover flies lay eggs near aphid colonies and parasitic Hymenoptera parasitize aphids in agricultural fields. In this study, we investigated the effect of interplanting two flowering plants, alyssum (*Lobularia maritima*) and cilantro (*Coriandrum sativa*), in a broccoli field (*Brassica oleracea*) to attract adult hover flies and parasitic Hymenoptera and enhance biological control of the cabbage aphid (*Brevicoryne brassicae*) and the green peach aphid (*Myzus persicae*). Adult hover fly activity was monitored with yellow pan traps and hover fly egg intensities and aphid intensities were assessed by counts from randomly pulled broccoli leaves. The percentage of aphids parasitized by Hymenoptera was assessed by counting numbers of mummified aphids on broccoli leaves. *Toxomerus occidentalis* and *T. marginatus* were the two most abundant hoverflies caught in yellow pan traps. Throughout the season significantly more adult hover flies were caught in pan traps in plots with alyssum than in plots with cilantro or control plots. The trend over the season was toward more adult hover flies caught in pan traps extending from alyssum plots up to 13.6 m into the adjacent field than from cilantro or control plots. Although aphid densities did not differ among treatments, a higher percent of the aphids in plots of alyssum were parasitized by Hymenoptera than in plots with cilantro or control plots. Significantly more hover fly eggs also were found in plots with alyssum than plots with cilantro or control plots on the second to last sampling date. Evidence of an association between hover fly egg laying and aphid intensities suggests that eggs were not laid until late in the season because aphid populations had not built up to a critical point earlier. Implications for the effectiveness of hover flies and parasitic Hymenoptera as biocontrol agents and the value of floral interplantings are discussed.

Introduction

The cabbage aphid *(Brevicoryne brassicae)* and the green peach aphid (*Myzus persicae*) are economically important insect pests of broccoli (*Brassica oleracea*) in the Pacific Northwest. Although aphids may stunt growth by feeding from leaf tissue, the main concern is product contamination when aphids enter the broccoli head (University of Ca. Ext. Pub, 1990).

The larvae of many species of hover flies are voracious aphid feeders and have the potential to limit aphid population growth (Chambers and Adams 1986). Several species of hover fly larvae are known to feed on cabbage aphids in England and New Zealand (van Emden 1965, Chandler 1968, White et al. 1995). In England, *Diaeretiella rapae* is the only known primary parasite of cabbage aphids (Kelm, 1988) and in California it is the most important parasite of the cabbage aphid and green peach aphid in cole crops (University of Ca. ext. pub. 1990). In Oregon, however, no studies have previously been conducted in broccoli and little is known about the role hover fly larvae and Hymenopteran parasitoids play in aphid populations dynamics.

Hover fly and Hymenopteran adults feed on pollen and nectar and are attracted to flowering plants. Amino acids from pollen are necessary for reproductive success, and carbohydrates from nectar provide energy resources (Schneider 1948). Surveys of weed and wild plant compositions have associated higher numbers of hover fly and Hymenopteran adults with field margins rich in flowering plants (Leius 1967, Cowgill

1989, Ruppert and Molthan 1991, Cowgill et al. 1993). Modern agricultural practices, such as frequent cultivation and herbicide regimes, can create farmscapes with reduced floral resources limiting the potential of hover flies and parasitic Hymenoptera for biological control.

Several studies have shown how planting flowering plants in or around farm fields to attract hover flies and parasitic Hymenoptera can enhance biological control in the adjacent field (Van den Bosch and Telford 1964, Leius 1967, Harwood et al. 1992, Holland et al. 1994, White et al. 1995, Hickman and Wratten 1996). Results have been inconsistent from year to year, however, and timing of attraction with critical periods of biological control has been identified as a key requirement for success (White et al. 1995, Hickman and Wratten 1996).

Hover flies and parasitic Hymenoptera exhibit selectivity for the flowers from which they feed (Leius 1960, Cowgill 1993, Lovei et al. 1993). In local trials we have found alyssum and cilantro highly attractive to local species of hover flies (Colley and Luna, unpublished data). Cruciferous plants in general are attractive to hover flies, as has been documented in Europe (Wnuk et al. 1991), and alyssum was used in an interplanting study in California by Chaney to attract hover flies and parasitic Hymenoptera (reported by Grossman and Quarles 1993). Trials in Europe and New Zealand demonstrated that hover flies preferred cilantro in the presence of several other flowering plants (Lovei et al. 1992, Macleod 1993). Jervais et al. (1993) also found a strong association between umbelliferous plants and parasitic Hymenoptera. These two plant species were chosen in part because they are easy to transplant and bloom early from seed.

The purpose of this study was to investigate the potential for planting either alyssum or cilantro in a broccoli field to attract adult hover flies and parasitic Hymenoptera, enhance hover fly oviposition in the field, and increase hover fly larval predation and Hymenopteran parasitism on aphids.

Materials and Methods

On-farm Interplanting Trial.

Alyssum and cilantro were interplanted with broccoli in a field study, in 1997, at Stahlbush Island Farms, near Corvallis, OR. The soil was a silty clay loam classified in the Chahealis soil series. In 1996, wheat was grown at the study site, followed by a winter annual cover crop of monida oat and common vetch. Spring of 1997 the cover crop was killed with Glyphosate and the field was then tilled with a disk, chisel plow, and rotera. Following tillage, broccoli and flowering plants were planted into the field.

The three treatments included: a broccoli monoculture, cilantro interplanted within the broccoli rows and alyssum interplanted within the broccoli rows. Plots were 18.3 m x 18.3 m with 22.9 m of row space between adjacent plots. The experimental design was a complete randomized block design, with 3 replications, arranged linearly within a 4 ha broccoli field.

Field borders were composed primarily of blackberry plants and deciduous trees with few other dicotyledenous species present. No flowering plants were noted adjacent to the field other than some wild cucumber growing in the blackberry bushes.

In previous studies researchers have drilled field margins with flower seed. Since broccoli is commonly transplanted in local fields we transplanted 8-wk old flowering plants, instead of direct seeding, to provide floral resources earlier in the season. Flowering plants were started in the greenhouse on 25 March and transplanted along with the broccoli on 23 May. Broccoli plants were spaced 37.5 cm apart in the row and rows were planted 91 cm apart. Cilantro was planted between every third broccoli plant in every other row. In plots with alyssum, 4 strips of broccoli were removed and planted with alyssum. Alyssum strips were 4 m long and placed 2.4 m from plot edge in every fifth row.

Adult Hover Flies.

Traps similar to those described by White et al. (1995) and Hickman and Wratten (1996) were used to monitor adult hover fly populations. The traps were 15 cm diameter plastic bowls, painted florescent yellow, a color demonstrated to be highly attractive to adult hover flies (Finch, 1992). Traps were filled with water, with a few drops of liquid soap (Ivory®) to reduce surface tension. Traps were placed on the soil surface between the broccoli rows in the center of each plot. Traps were also placed in the field adjacent to each plot, along a transect perpendicular to the linear arrangement of plots, at the plot edge,: 6.4 m from the plot, 13.7 m from the plot, and 27.4 m from the plot. Traps were placed in the field and collected two days later on five dates: 22 June, 25 July, 5 July, 19 July, and 25 July. Hover flies caught were stored in 70% ethanol and later counted and identified to species and sex. Adult female hover flies were dissected and the presence or absence of eggs was recorded.

Aphid Populations.

Aphid populations were monitored weekly from the fifth week after planting, when aphids were first found in the field, until harvest. The two main aphid species in broccoli in Oregon are the cabbage aphid, *Brevicoryne brassicae*, and the green peach aphid, *Myzus persicae*. Standard walks were conducted in each plot to collect 60 randomly picked leaves, 20 new leaves, 20 leaves of an intermediate growth stage, and 20 old leaves. The bags of leaves were brought back to the lab and aphids were removed from leaves and counted. The number of aphid mummies, parasitized by Hymenoptera, also were recorded. Hover fly egg and larvae intensities were estimated weekly by searching collected broccoli leaves.

Statistical Analysis.

Analysis of variance procedures and mean separation tests were conducted using the Statistical Analysis Software (SAS, 1990). Least square means procedure was used for comparing among treatment means by individual dates. Numbers of adult hover flies, numbers of gravid female hover flies and numbers of hover fly eggs were transformed by square root + 0.5 before analysis to improve the homogeneity of variances. Numbers of aphids were transformed by log10 + .05 to improve homogeneity of variances. An alpha level of 0.05 was used as a rejection criteria for hypothesis testing.

Numbers of adult hover flies, gravid female hover flies and hover fly eggs were compared across the season, as repeated measures, by split-plot analysis with flowers as main plots and dates as subplots (Little and Hills 1978). This analysis was only conducted when there was no significant flower by date interaction.

Results

Adult Hover Flies.

Of a total of 563 hover flies caught, 51% were *Toxomerus occidentalis* and 36% were *T. marginatus*. The remaining 13% included *T. politus, Sphaerophoria sulphuripes, Eupeodes fumipenis,* and *Syrphus opinator*. Eighty-one percent of all hover flies caught were female and 19% were male.

Over the season, more *T. occidentalis* were caught in plots of alyssum than cilantro or control plots ($F = 8.12$; $df = 2,2$; $p < 0.01$). There is also suggestive evidence that more *T. marginatus* were caught in plots with alyssum than plots with cilantro, but no differences were found between plots with alyssum or cilantro and control plots (F = 1.89; df = 2, 2; p < .10) (Fig. 3.1, Fig. 3.2). Alyssum and cilantro plants were in bloom on all sampling dates.

Table 3.1. Total number of aphidophagous hover flies caught in pan traps from 22 June to 25 July, 1997

	Species						
	T. occidentalis female	*T. occidentalis* male	*T. marginatus* female	*T. marginatus* male	Other female	Other male	Total
Alyssum	107	9	78	15	21	10	240
Cilantro	79	8	51	6	13	1	158
Control	69	15	46	7	24	4	162
Total	225	32	175	28	58	15	

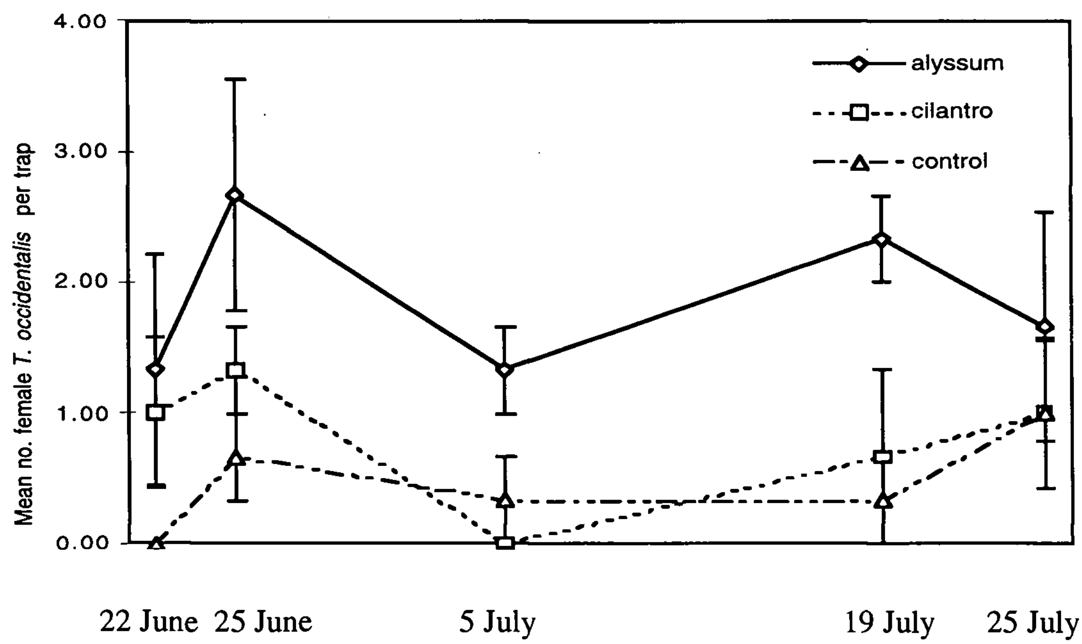

Fig. 3.1. Mean number of female *T. occidentalis* caught in pan traps in treatment and control plots from 22 June to 25 July, 1997.

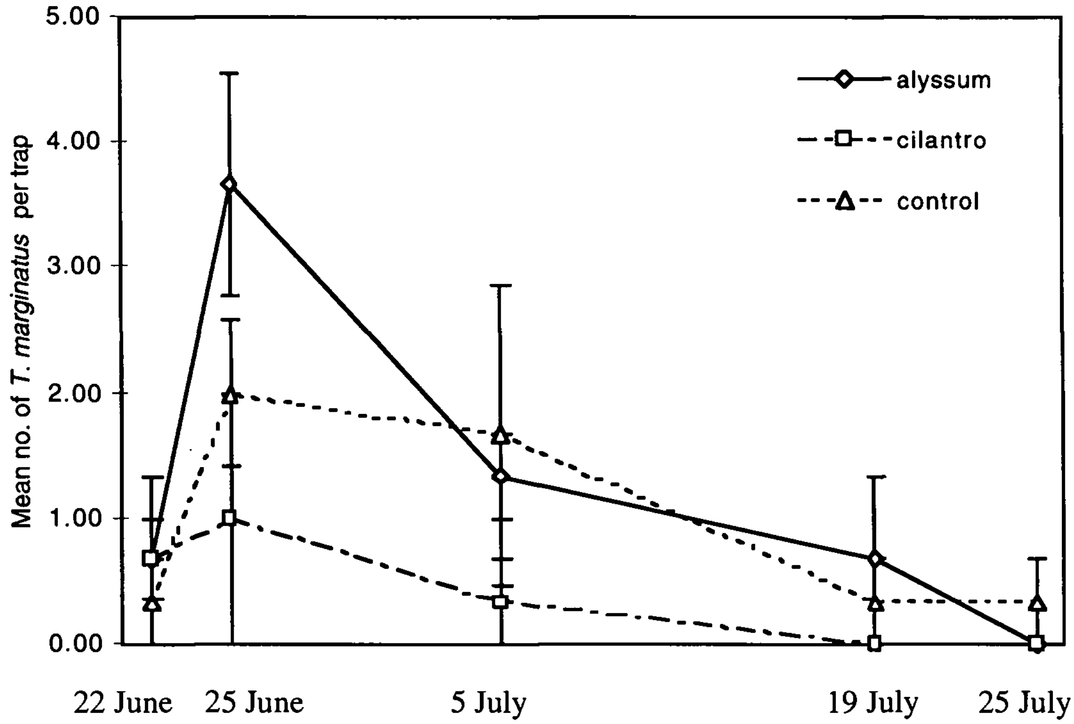

Fig. 3.2. Mean number of female *T. marginatus* caught in pan traps in treatment and control plots from 22 June to 25 July, 1997.

Overall, numbers of flies caught at different distances from plots did not differ among treatments. However over the entire season there was a trend of higher numbers of flies caught in pan traps extending up to 13.7 m into the field adjacent to alyssum plots (Fig. 3.3).

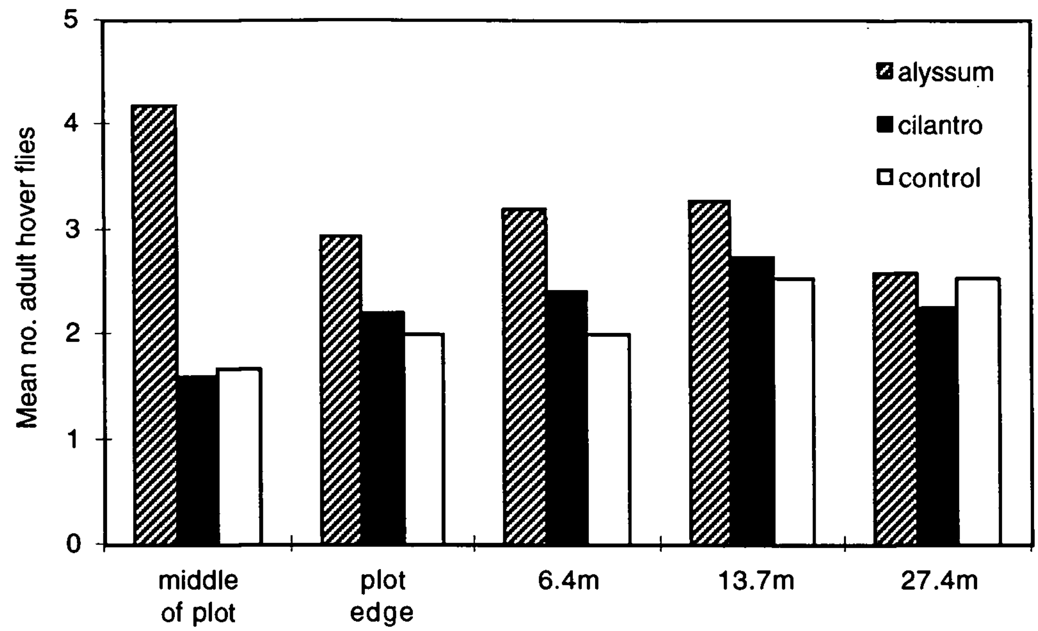

Fig. 3.3 Mean number of adult hover flies caught in treatment and control plots and at varying distances into the adjacent field.

Gravid Female Hover Flies.

Gravid female hover flies were present on every sampling date (Fig. 3.4, Fig. 3.5). There is suggestive evidence that, over the season, more gravid *T. occidentalis* were caught in plots of alyssum than in plots with cilantro or control plots ($F = 1.19$; $df = 2,2$; $p < 0.10$). On 5 July more gravid *T. occidentalis* were caught in plots with alyssum than in plots with cilantro or control plots ($F = 5.44$; $df = 2,2$; $p < 0.05$) (Fig. 3.4). Numbers of gravid *T. marginatus* were not analyzed across the season because there was a significant date by treatment interaction, but analysis by date shows that ,on 25 June, the date of peak *T. marginatus* catches (Fig. 3.2), more gravid *T. marginatus* were caught in plots with alyssum than in plots with cilantro or control plots ($F = 17.22$; $df = 2,2$; $p < 0.05$) (Fig. 3.5).

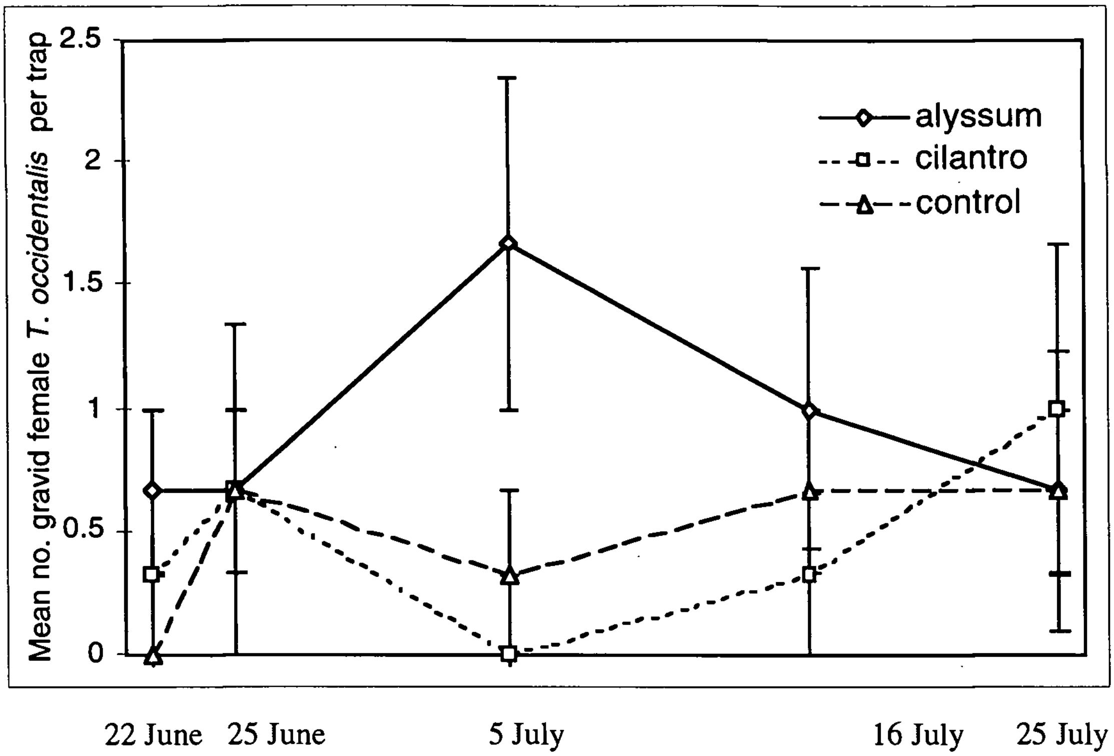

Fig. 3.4. Mean number of gravid female *T. occidentalis* caught in pan traps in treatment and control plots from 22 June to 25 July, 1997.

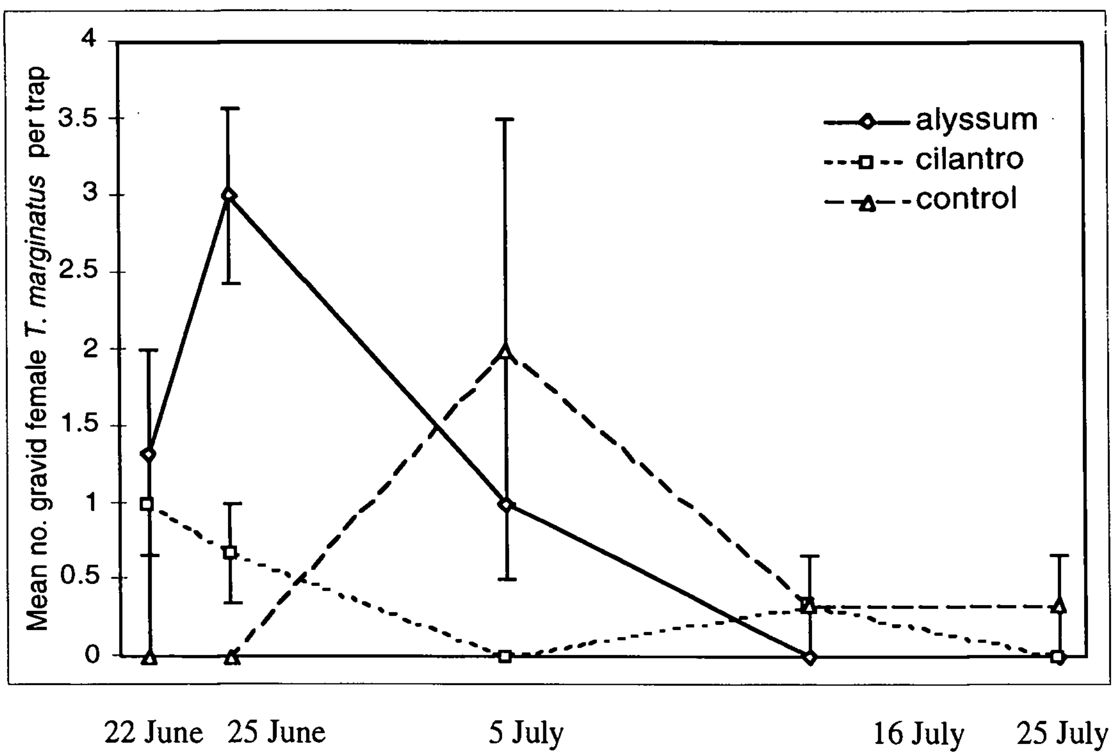

Fig. 3.5 Mean number of gravid female *T. marginatus* caught in pan traps in treatment and control from 22 June 25 July, 1997.

Hover Fly Eggs and Larvae.

Hover fly eggs were only found on broccoli leaves on 16 June and 25 June, the last two sampling dates. More hover fly eggs were laid in alyssum plots than cilantro or control plots on 16 June ($F = 5.65$; $df = 2,2$; $p < .05$) (Fig. 3.6). Very few hover fly larvae were found on broccoli leaves and no differences in numbers of hover fly larvae were found (data not shown). However, on both 16 June and 25 June we observed hover larvae feeding on aphids on broccoli leaves.

A subsequent comparison of mean numbers of hover fly eggs per leaf and mean densities of aphids per leaf suggest that there is an association between aphid densities and the number of hover fly eggs laid (Fig. 3.7). There appears to be an aphid density threshold, below which few hover fly eggs are laid.

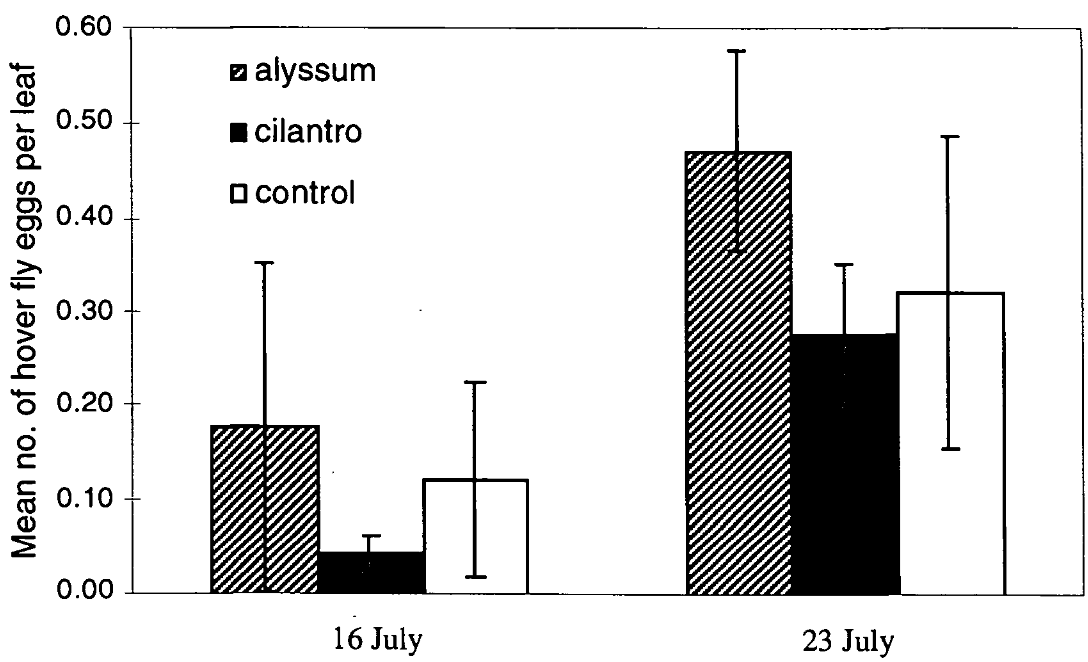

Fig. 3.6. Mean number of hover fly eggs found on broccoli leaves in treatment and control plots on 16 July and 23 July, 1997.

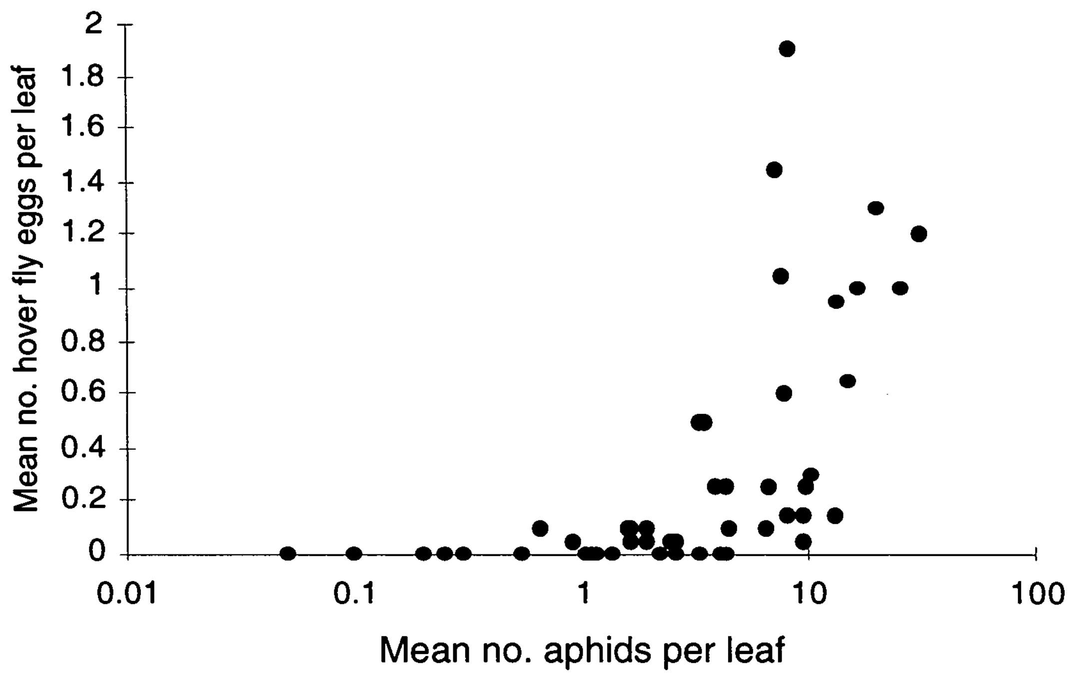

Fig. 3.7. Relationship between the mean number of hover fly eggs per broccoli leaf and the mean number of aphids per broccoli leaf.

Aphids.

Aphids did not appear in the field until 4 weeks after planting. There were no significant differences in aphid intensities of *M. persicae* in treatment and control plots across the season or on any sampling date (Fig. 3.8). Counts suggest that there were more *B. brassicae* in plots with alyssum than in control plots on 16 June (Fig. 3.9) ($F = 3.02$; $df = 2,2$; $p < 0.10$), however, the mean number of aphids found in one of the blocks of alyssum on that date was an obvious outlier.

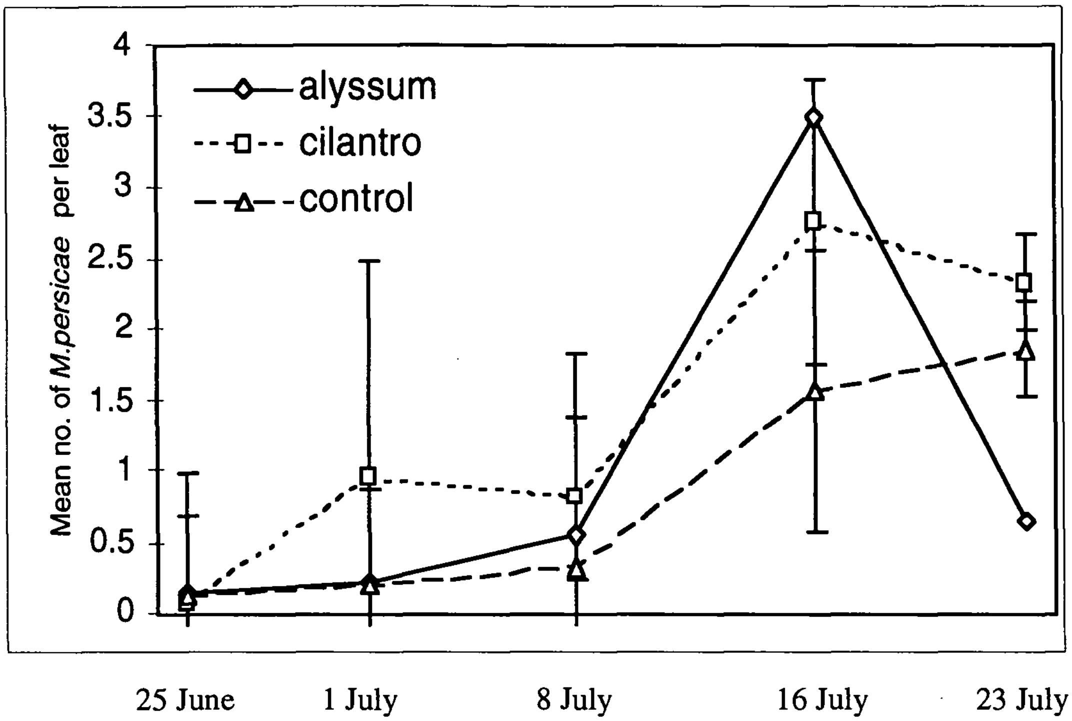

Fig. 3.8. Mean number of *Myzus persicae* per broccoli leaf in treatment and control plots from 25 June to 23 July, 1997.

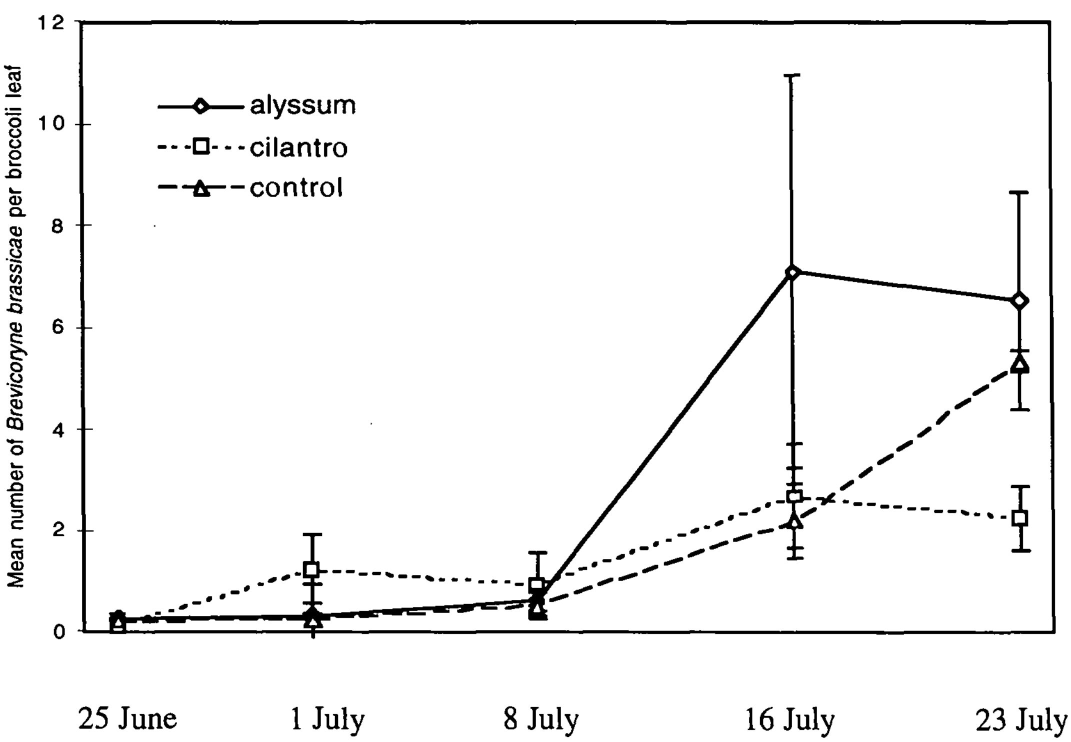

Fig. 3.9. Mean number of *Brevicoryne brassicae* per broccoli leaf in treatment and control plots from 25 June to 23 July, 1997.

Parasitic Hymenoptera.

The presence of alyssum appeared to affect the activity of parasitic Hymenoptera. Over the season, the percentage of aphids parasitized by Hymenoptera in plots with alyssum was greater than in plots with cilantro or control plots ($F = 4.54$; df = 2,2; $p < 0.01$). The most pronounced affects of alyssum occurred during the last two sampling dates when aphids were the most abundant (Fig. 3.10). There were no detectable effects of cilantro on parasitism rates compared to the control.

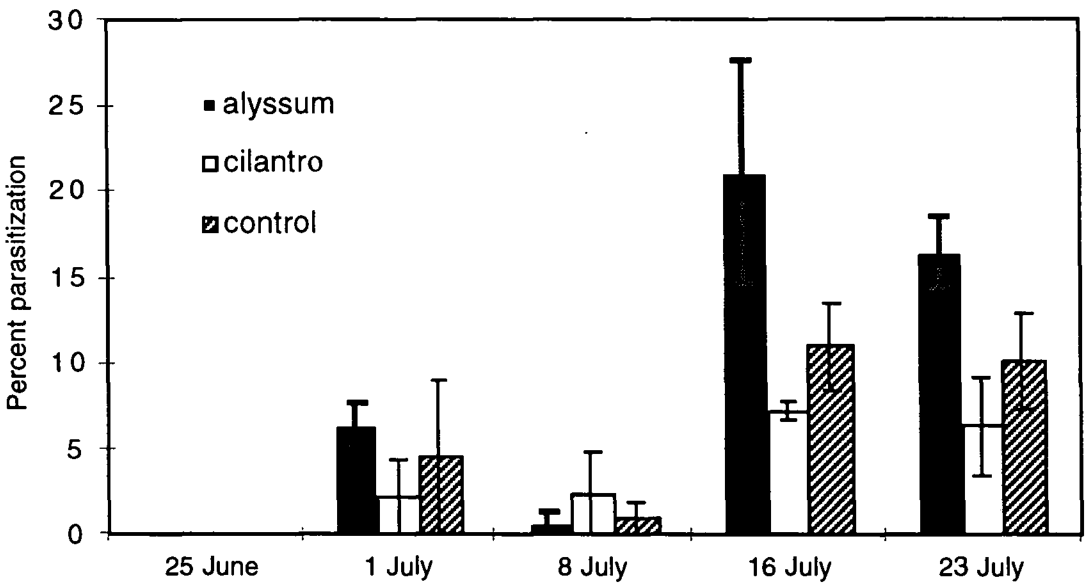

Fig. 3.10. The percentage of aphids parasitized by Hymenoptera on broccoli leaves in treatment and control plots from 25 June to 23 July, 1997.

Discussion

If the presence of flowering plants enhances the effectiveness of aphidophagous hover flies and parasitic Hymenoptera as biological control agents, we would expect to find more adult hover flies present, greater numbers of hover fly eggs laid in the crop, and fewer aphids present as a result of increased larval predation and Hymenopteran parasitism. We found evidence of increased numbers of hover fly adults and higher numbers of hover fly eggs, and increased levels of parasitism but did not find fewer aphids. Similar studies that investigated the effects of providing floral resources to enhance hover fly activity have likewise found pieces of evidence, but results have been inconsistent from year to year. White et al. (1995) found increased numbers of hover fly adults and fewer aphids in plots with floral boundaries, but no differences in hover fly eggs were detected. In a two-year study, Hickman and Wratten (1996) found all three pieces of evidence, but not all in the same season.

Our results indicate that numbers of adult female *T. occidentalis* and *T. marginatus* and numbers of gravid female *T. occidentalis* and *T. marginatus* increased in the presence of alyssum, but not cilantro. These results differ from previous studies which have found cilantro attractive to hover flies (Loveii et al. 1993, Macleod 1994). Two possible explanations are that either cilantro is not attractive to these species of hover flies, or that alyssum was even more attractive and acted as a magnet drawing numbers of foraging flies from other plots. It is also possible that other species of hover flies were attracted to cilantro plots but were not attracted to the yellow pan traps.

This was the first experiment conducted in Oregon in which hover fly species associated with agricultural fields were identified. Another experiment was conducted nearby in the same season, (see chapter 2) in which hover flies were surveyed with sweep net catches. In that study, we caught twenty species of hover flies, but in this study the majority of hover flies caught were in two species, *T. occidentalis* and *T. marginatus*. Unless the pan traps used were selectively attractive to flies in the genus *Toxomerus*, it appears that locally this is the dominate genus associated with broccoli. Our results suggest that *T. occidentalis* in particular was attracted by alyssum. A species-specific interaction may be occurring between *T. occidentalis* and alyssum suggesting that if *T. occidentalis* is an important biological control agent then planting alyssum may be a useful tactic to enhance the activity of this natural enemy.

If the presence of flowering plants does increase local numbers of adult hover flies, then a critical question is how far will the affect be extended into the adjacent field. We dispersed flowering plants into the crop field, while other studies have concentrated the floral resource in strips adjacent to the field. Lovei et al. (1993) investigated hover fly dispersal and field penetration from flowering strips and estimated the effect of flowering strips increased hover fly numbers up to 15 m into the adjacent field. Hickman and Wratten (1996) found a consistent trend, though not statistically significant, of more hover flies caught at distances up to 180 m into fields bordered by phacelia than in fields without phacelia. Conversely, White et al. (1995) found more hover flies associated with borders of phacelia, but almost all of the flies were caught within 0.5 m from the flowering strip. Our results were most similar to Loveii et al. (1993). A trend of higher numbers of hover flies in alyssum plots extended to 13.7 m into the field, but then seemed to reach parity at 27.4 m (Fig. 3.3). Our plots were 18.3 m wide and away from the edge of the field so the affected area may have been as wide as 45 m total. However, as have pointed out, dispersal behavior of hover flies apparently varies among species.

If the effects of flowering plants extended to no more than 13.7 m from plot edges, then we can assume that the 22.9 m of spacing between plots was sufficient distance to separate treatment effects. Therefore any observed differences in hover fly numbers could be attributed to the presence of the flowering plants.

Increasing egg laying in the crop field is the key to enhancing biological control since it is the immature hover fly which is predaceous. However, many studies have found either increased numbers of hover fly eggs, or decreased numbers of aphids, but not both. One probable reason is that gravid female hover flies exhibit both aggregative (Sanders, 1979) and reproductive (Banks 1953, Dixon, 1959, Chandler, 1968b) numerical responses. In our study, aphid densities did not differ between treatments, but more eggs were found in plots of alyssum. If aphid populations truly were not different throughout the field, then the increased numbers of hover fly eggs found in the alyssum plots could be attributed to the presence of alyssum rather than to a numerical response to different aphid densities.

Our experiment was not designed to test the hypothesis that hover flies exhibited numerical responses in ovipositing. However, by comparing the mean number of aphids per leaf to the mean number of hover fly eggs laid per leaf we find evidence of an association between the two (Fig. 3.7). Because *B. brassicae* are highly aggregated in their distribution among leaves (Heathcote, 1972), and our estimates of mean aphid densities were calculated from aphids on 60 leaves per plot, an interpretation of the data is difficult. However, it appears that there is an aphid density threshold below which few eggs are laid. Hover fly eggs were not found in the crop until 16 July, yet gravid females were present in the field on all sample dates. This evidence suggests that hover fly eggs were not laid in the field before 16 June because aphid densities were too low to induce oviposition.

Although hover fly eggs found were not taxonomically classified beyond the family Syrphidae, our results indicate that the ovipositing species laid eggs in response to the presence of aphids , a behavior termed aphidozetic by Chambers (1968). All of the hover fly eggs were found on the underside of broccoli leaves either near or in aphid colonies. Since we are not certain that *T. occidentalis* was the ovipositing genus, it would be useful to conduct laboratory studies to assess the ovipositing behavior of this species to identify whether or not it is aphidozetic. Many aphidozetic species (e.g. *Episyrpus balteatus*) are considered important aphid predators because the placement of eggs near aphids and the numerical response of laying more eggs at higher aphid densities may intensify the predatory activity where the pest population is greatest.

Both the broccoli and flowering plants were planted on 23 May. Aphid densities were not sampled until 25 June because very few aphids were present in the crop. According to a local farm advisor, aphid infestations were relatively light and started later in the season than in many years (Andy Bennett, pers. com.). Populations remained relatively low throughout the season and differences were not detected between treatments. One probable reason for a lack of differences is that egg laying did not occur until late season so hover fly larvae were not present until just before the end of the sampling period. We are unable to predict what effect the presence of flowering plants would have had if aphids densities had been higher or had appeared earlier in the season.

A greater percentage of the aphids found in alyssum plots were parasitized by Hymenoptera than in cilantro or control plots. Although higher levels of parasitism did not result in lower numbers of aphids present these results suggest that the presence of alyssum has potential to enhance parasitoid activity. If this type of habitat manipulation can enhance the activity of multiple natural enemies at once, then these cumulative effects should be considered in assessing the potential for enhancing biological control.

Synchronicity of several factors including: available pollen and nectar, arrival of natural enemies, critical periods of pest population growth and crop phenology has been suggested as determining whether predation and parasitism will effect aphid populations (White et al. 1995, Hickman and Wratten 1996). In our case, it appears that timing of pest population growth limited the timing of hover fly predation. Our results indicate, however, that the numerical abundance of both egg and adult hover fly activity as well as rates of Hymenopteran parasitism were enhanced by the presence of alyssum. Although planting flowers in farm fields is not a guarantee of aphid control, in a year when timing occurs it may aid in increasing the predator/ prey ratio and play a role in an integrated crop protection program. Considering the potential pest reduction benefit, coupled with the relative ease of establishment and public and regulatory pressure to reduce pesticide use, we feel this type of natural enemy augmentation warrants further investigation.

Acknowledgments

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Chapter 4

Conclusions

Every farm field is an agroecosystem and as managers of that system we influence the ecology and species composition of the insects in it. Modern agricultural practices, such as frequent cultivation and herbicide applications, along with the expanse of monoculutral production, have created agricultural landscapes in which resources needed by insect natural enemies may be limited or unavailable. Wratten and van Emden (1995) have suggested that the survival and activity of natural enemies can be enhanced by habitat manipulation which provides appropriate physical and biotic resources where they have been removed or depleated. The goal of benefical insectary planting is to increase the availability of pollen and nectar, two biotic resources needed by certian natural enemies in agroecosystems.

There are two scales on which beneficial insectary plantings may have an effect on natural enemy populations. On a local scale, the presence of flowering plants and avialability of pollen and nectar may attract natural enemies and enhance their activity in the adjacent fields. On a larger scale, the availability of pollen and nectar may enhance the survival and activity of natural enemies on a regional scale as well as through time. Quantifying effects on this larger scale would be difficult, but could have important implications for regional habitat management programs. It is likely that several, naturally-occurring flowering plants serve as pollen and nectar resources for natural enemies. By identifying critical time periods in which floral resources are limited in availability one could potentially enhance the survival of natural enemies by providing resources durring these windows of time. We did not investigate the effects of beneficial insectary planting on this larger scale. The studies we conducted assessed the attractiveness of selected flowering plants to aphidophagous hover flies and parasitic Hymenoptera and the potential of effecting the activity of natural enemies on a local (farm field) scale.

Although many flowering plants are promoted by gardening magazines and seed companies as attractive to beneficial insects, few of these plants have been scientifically evaluated. In Chapter 2 of our research we conducted three experiments to identify particular plant species attractive to aphidophagous hover flies and parasitic Hymenoptera. We chose the plants for our trials from gardening information sources and from plants used in previous scientific research. Our results indicated that cilantro, alyssum, mustard, phacelia, and buckwheat were particularly attractive to aphidophagous hover flies. Of the plants evaluated, agastache, mustard, and yarrow appeared to be the most attractive to parasitic Hymenoptera.

In this study, the measure of hover fly visiting frequencies, and abundace of Hymenoptera collected, were used as a measure of attractiveness of the associated flowering plants. We did not, however, identify specific mechanisms involved in attractiveness. In general, insects are known to be attracted to flowering plants by a variety of mechanisms including color, odor, height, and floral morphology. Research which identified specific mechanisms of attraction would be useful in identifying characteristics of attractive plants. Plants with these characteristics could then be included in future evaluations. Identifying several attractive plant species is important because, as flowering phenologies vary, providing floral resources throughout the season may require utilizing several plant species.

Because pollen provides proteins needed for egg maturation in female hover flies and parastic wasps, increasing pollen availability by providing floral resources may enhance egg laying in gravid females. Certian plant species may provide more nutritious foraging resources than others . Assessing the relative quality of the pollens from particular insectary plants may therefore help identify plants most effective in enhancing egg laying activity. .

Attracting natural enemies to flowering plants in or around farm fields may increase the number of natural enemies present in the vacinity of crop plants. Attraction alone may not, however, lead to enhanced natural enemy activity if the floral resources are unsuitable for feeding. Pollen and nectar are not available to all species of insects from all species of flowering plants. Honeybees, for example, are known to attempt to feed from certian flowers without recieving a pollen or nectar reward. It is unknown if foraging hover flies make repeated, unsuccessful feeding attempts. If they do, then observations of visiting frequencies may be missleading in quantifying relative attractiveness. Foraging hover flies may make more frequent, unsuccessful feeding visits, while hover flies successfully feeding from a flower species may sooner reach satiation and visit fewer flowers. Observations of feeding visits which documented hover flies recieving pollen or nectar might better identify beneficial insectary plants which effecively provide needed resources.

The activiy of hover flies is known to vary with the time of day and factors such as temperature and wind speed (Gilbert, 1985). In this study we conducted our observations and vaccumm sampling from 10:00 am to 12:00 am for standardization. In England, this time period has been observed to be the time of peak daily activity and was therefore chosen in hopes of observerving the greatest number of hover flies. It is unknown if the peak of hover fly activity occurs durring this time in Oregon. If timing of activity varies among species, then certian species of hover flies may have been underassessed, or not included, in our observations.

Although species-specific interactions were not assessed in this study, through observations it was apparent that attractiveness of flowers to hover flies varied among hover fly species . Once hover fly species are identified as important predators of specific pests, studies could be conducted to focus on attracting these species in particular.

During the spring and summer of 1997 we captured adult hover flies with sweep nets to survey the local fauna associated with agricultural field and with our particular flowers of interest. Reference specimens of captured species were identified by Christian Kassebeer. Twenty species were identified, 15 of which are aphidophagous. These species will be eventually be submitted to the OSU Entomology Library as part of a permanent collection.

In Chapter 3 of our research we conducted a replicated, on-farm experiment at Stahlbush Island Farm to test the hypothesis that interplanting flowering plants in a farm field could enhance hover fly and parasitic Hymenopteran activity leading to enhanced biological control of the cabbage aphid and green peach aphid. Our results indicated that the presence of alyssum enhanced hover fly and parasitic Hymenopteran activity, however, we found no differences in aphid abundance between treatments. Both hover fly eggs and parastitized aphids did not appear in the crop until late in the season suggesting that the lack of differences in numbers of aphids present could be attributed to the late activity of these natural enemies. By comparing the mean numbers of aphids per leaf with the mean number of hover fly eggs per leaf, we found evidence of an aphid density threshold, below which few hover fly eggs were laid. The mean number of aphids per broccoli leaf did not reach this "threshold level" until late season. It appears, from our results, that the timing of pest population growth may be a critical factor in hover fly egg laying activity.

In the 1997 growing season, overall, aphid pressure was low. It is unknown whether significant hover fly larval predation would have occurred had aphid infestations been higher or occurred earlier in the season. The crop in which our study was conducted had no measurable economic damage as a result of aphids although the only pesticide sprayed was a low-dose pyrethroid 1 week before harvest. Broccoli is a high value crop with low tolerance for aphid infestations. We recognize that insectary plants may not provide complete pest control, but an insectary planting may offer aid in tipping the predator/prey ratio and allow growers to opt for "softer" chemical control methods as part of an integrated control strategy.

Knowledge of hover fly egg-laying thresholds is important in understanding the predator/ prey dynamics which effect their capacity in biological control. Chandler (1968) identified species of hover flies as either ovipositing in response to aphids (aphidozetic) or in response to plant cues (phytozetic). Brandenburg and Powell (1992) showed that olfactory cues from aphid honeydew act as an ovipositional stimulant for certain species of hover flies, but not for others. Different species of hoverflies begin laying eggs, and reach a peak in oviposition, at different aphid densities (Chandler 1968). Testing the hypothesis that *T. occidentalis* and *T. marginatus,* the two predominate species caught in our study, are aphidozetic species and identifying an aphid density threshold could be accomplished by artificially infesting broccoli plants with known aphid densities and monitoring subsequent oviposition rates. This information could contribute to the development of pest and predator monitoring protocols by assessing at what aphid densities hover fly predation may contribute to aphid biological control.

Clearly, there is a complex ecology involved which affects the activity of natural enemies and their potential role in pest population dynamics. Benefical insectary planting is not a consistently predictable method of biological control. However, natural enemies can be important in the regulation of pest populations and beneficial insectary planting, used in conjuction with other integrated pest management strategies, has promise in enhancing the activity of natural enemies in agroecosystems.

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Appendix

Appendix

Beneficial Insectary Planting: 1996
Oregon State University Vegetable Research Farm

In 1996 we established a beneficial insectary screening trial and began or development of sampling methods along with a preliminary screening of attractiveness of insectary plants. Visual observations were made of hover flies visiting flowering plants and vacuum samples were taken from flowering plants to assess parasitic Hymenoptera and flowering plant associations. Statistical analysis was not conducted because sampling was not completed in all blocks on a given date. Since attractiveness is highly variable from date to date, depending on weather, time of day, and floral and insect phenologies, we could not conduct analysis across dates. Mean numbers of hover flies and parasitic Hymenoptera were calculated across the season to get a general idea of which plants showed promise as attractive species. Because this experiment was a preliminary screening trial, this experiment is presented in the Appendix of this thesis rather than as a chapter. In general, alyssum, calendula, and mustard all showed promise as attractors of hover flies and parasitic Hymenoptera appeared to have an association with agastache. These plants were included in our continued evaluations in 1997.

The relative attractiveness of flowering plants to beneficial insects.

Annual plants	mean no. hoverflies/m^2/10 min.	mean no. hymenoptera/ 1 min. AVAC sample
Mustard	8.3	0.5
Calendula	8.4	1.6
Alyssum	11.9	1.9
Phacelia	2.0	1.8
Atriplex	0.0	n/a
Perennial plants		
Agastache	1.8	2.3
Yarrow	6.0	1.8
Buddlea	0.3	n/a

Blooming periods of flowering plants

Annual plants	date planted	date of 1st bloom	date of peak bloom
Mustard (tr)	6/20	7/25	7/31
Calendula (tr)	6/13	7/13	8/5
Alyssum (tr)	6/21	7/1	8/1
Phacelia (ds)	6/19	7/31	8/25
Atriplex (tr)	6/20		
Perennial plants			
Agastache (tr)	6/6	7/28	8/23
Yarrow (tr)	6/6	7/25	8/25
Buddlea (trg)	6/20	7/25	8/20

*tr=transplanted 2 in. container
*ds=direct seeded
*trg=transplanted gallon pot