ABSTRACT

Title of Document:	BIODIVERSITY AND CONSERVATION BIOLOGICAL CONTROL: DO GRASS FILTER STRIPS WITH WILDFLOWERS ENHANCE NATURAL ENEMIES IN NEIGHBORING CROP HABITATS?
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Grass buffer strips are commonly deployed along crop borders in North American agricultural landscapes. Such borders filter nutrient and pesticide runoff to neighboring habitats and foster biodiversity. The addition of wildflowers in these strips to provide nectar and pollen resources can positively impact natural enemies of crop pests, particularly hymenopteran parasitoids. I investigated the presence/absence of wildflowers on natural enemy abundance in buffer strips and in neighboring soybean fields in 2005 and 2006. I predicted that wildflowers would attract and act as a source of natural enemies which would then disperse into neighboring crop fields.

In both years, sticky cards were used to measure the abundance of aerial arthropods in pure stands of wildflowers and in neighboring soybean plots. Pitfall traps were also used in 2006 to measure abundance of epigeal taxa. In the 2005 experiment, sticky card captures of hymenopteran and dipteran parasitoids were 72.7% higher in buffers containing partridge pea compared to the other buffer types.

Similarly, communities of all beneficial arthropods captured by sticky card and pitfall traps in 2006 were significantly 79.8% to 72.3 % higher, respectively, in the partridge pea buffers compared to communities in the soybean crop. However, buffer effects on populations of parasitoids and predators in the neighboring crop were mixed in both experiments depending on the particular functional group and specific family of arthropods. Results suggest that partridge pea was a source for canopy-dwelling dipteran parasitoids and saprovores, but acted as a sink for canopy-dwelling mymarids, canopy-dwelling predators and ground-dwelling ants, and had a neutral effect on all others. However, these effects did not extend far into the soybean crop and were generally not discernible beyond 6m.

This study provides evidence that a pure stand of an attractive source of floral resources in a bordering non-crop area may not be desirable for enhancing conservation biological control. The species of flower and desired natural enemy should be taken into consideration before determining the mix of plant species to include in a buffer strip.

BIODIVERSITY AND CONSERVATION BIOLOGICAL CONTROL: DO
BUFFER STRIPS WITH WILDFLOWERS ENHANCE NATURAL ENEMIES IN
NEIGHBORING CROP HABITATS?

By

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Dedication

This thesis is dedicated to the memory of Dr. Robert F. Denno, 1945-2008.

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Introduction

Managers of agricultural and ornamental systems have sought to manipulate habitat complexity to encourage the conservation and enhancement of natural enemies in the hopes of improving pest suppression (in reviews by Wratten and van Emden 1995, Gurr *et al.* 2005, Landis *et al.* 2000). Bianchi *et al.* (2006) reviewed 28 studies that quantified pest pressure and natural enemy populations in crops in relation to landscape composition. They reported that complex landscapes were correlated with higher natural enemy populations and lower pest pressure in 74 and 45% of the studies, respectively. They also found that herbaceous habitats increased natural enemy activity more than wooded habitats. A key factor that enhances predator and parasitoid populations in complex landscapes is the availability of nectar and pollen subsidies. Many natural enemies, particularly hymenopteran parasitoids, lacewings, syrphid flies, and tachinid flies are herbivorous as adults and require carbohydrates for successful reproduction. A literature review by Altieri and Letourneau (1982) showed that the successful establishment of certain parasitoids in cropping systems has depended on the presence of weeds that provided nectar for the adult female wasps.

Heimpel and Jervis (2005) developed the "parasitoid nectar provision hypothesis", which posits that the addition of nectar leads to increased pest suppression by parasitoids. Since agricultural monocultures generally lack floral resources and in many cases are virtually weed-free, the addition of a nectar source should increase parasitoid fitness and thus pest suppression. However, studies linking floral resources to increased biological control by parasitoids have had mixed results. Laboratory and field studies have demonstrated positive impacts on parasitoid fecundity, lifespan, or searching efficiency as a result of floral resources in bordering non-crop areas (Lavandero *et al.* 2006, Gourdine *et al.* 2005, Lee and Heimpel 2008, Bianchi and Wäckers 2008). In addition, there is increasing evidence that these food subsidies can ultimately lead to increased parasitism in adjacent crop fields (Zhao *et al.* 1992, Baggen and Gurr 1998, Stephens *et al.* 1998, Irvin *et al.* 2000, Morris and Li 2000, English-Loeb *et al.* 2003, Tylianakis *et al.* 2004, Ellis *et al.* 2005, Lavandero *et al.* 2005, Berndt *et al.* 2006, Winkler *et al.* 2006, Masetti *et al.* 2010). The majority of these studies have focused on floral understories in fruit crops and on buckwheat and a few other flowering plants as floral resources grown next to various cereal and Brassica crops. The hymenopteran parasitoids studied have for the most part been in the families Ichneumonidae and Braconidae, so it is not clear if other parasitoids would respond to floral resources in the same way. In addition to increased pollen and nectar, flowering plants can provide natural enemies with alternative hosts, shelter, and a more suitable microclimate (Landis *et al.* 2000). Over 60% of the alternative hosts of generalist parasitoids that suppress lepidopteran insects in grain and forage crops feed on woody and herbaceous vegetation in bordering non-crop areas (Landis & Menalled 1998). Studies have shown that the presence of alternative prey/hosts on flowering plants can improve natural pest control (Maier 1981, Settle *et al.* 1996).

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Positive impacts of floral resources on parasitoid populations and enhanced parasitism may not result in effective pest suppression. From a pest management viewpoint, the review by Bianchi *et al.* (2006) found only a small number of studies, in which the addition of floral resources in non-crop areas resulted in suppressed pest populations. Moreover, other studies have shown that floral resources have no effect on parasitism in adjacent crop fields (Berndt *et al.* 2002, Bell *et al.* 2006, Lee *et al.* 2006, Rebek *et al.* 2006, Wanner *et al.* 2006a, Vollhardt *et al.* 2010).

The favorable conditions, alternative hosts and food subsidies provided by flowering plants may have negative effects on pest suppression in several ways. A key assumption in conservation biological control is that the floral-rich non-crop areas confer a selective advantage to parasitoids over that of pests. However, the composition and diversity of certain bordering non-crop areas can favor pest species over natural enemies. In 15% of the studies reviewed by Bianchi *et al.* (2006), higher pest populations were associated with increasing landscape complexity. Lavandero *et al.* (2006) demonstrated that a combination of buckwheat and purple tansy conferred a selective advantage to parasitoids, while other plant combinations increased the fitness of both pests and parasitoids. Bone *et al.* (2009) reported that flowering ground covers did not increase natural enemy activity in apple orchards but showed evidence of increased pest and fruit damage with certain flowering plants. Similarly, Baggen and Gurr (1998) found that flowers led to increased parasitism by attracting more pests, which caused increased crop damage. An adjacent non-crop area with abundant host/prey and floral resources can also attract and retain natural enemies away from crop fields, thus act as a sink. Few documented cases of this have been reported. However, one study by Olson and Wäckers (2007) reported that field margins containing floral resources acted as a sink for trichogrammatid and tachinid parasitoids. Another negative effect to consider is that the particular parasitoids enhanced by floral resources could be harmful to other natural enemies. Intraguild competition and hyperparasitoids of the natural enemies may influence the success of natural enemy enhancement using floral resources. For example, several studies provide evidence that flowering border areas can increase lacewing egg parasitoids and thus disrupt biological control (Stephens *et al.* 1998, Robinson 2009).

Development of non-crop habitats with floral resources should consider the spatial scale over which increased parasitism and/or pest suppression extends into the crop. From an agronomic viewpoint, this helps in deciding the particular crop area to manage as well the cost-effectiveness of taking land out of production to increase biological control of pests. Parasitoid abundance (Platt *et al.* 1999) and parasitism rates (Baggen and Gurr 1998, Tylianakis *et al.* 2004) have been observed to decline in the crop as distance from a floral border increased. Parasitoid movement from flowering border areas also varies depending on the floral composition and particular parasitoid species. Parasitoids feeding on buckwheat flowers moved at least 30m into an adjacent vineyard (Scarratt *et al.* 2008), and led to increased parasitism 14m into neighboring wheat fields (Tylianakis *et al.* 2004) and 80m into neighboring broccoli fields (Lavandero *et al.* 2005). A study by Long *et al.* (1998) found that floral

resources caused braconid wasps to move from a flowering non-crop area into the neighboring crop, but this effect was not seen with trichogrammatids.

Herbivores and parasitoids may respond differently to floral resources (Patt *et al.* 1997; Baggen *et al.* 1999; Harvey and Wagenaar 2006), so both types of impacts must be taken into consideration when choosing which species of flowering plants to incorporate into an agricultural setting. Chaney (1998) ranked twenty-two flowering plant species, including alyssum, phacelia, buckwheat, broad bean and coriander, for their potential use as insectary plants based on their attractiveness to beneficial insects and pest species. For example, alyssum showed the greatest potential because it flowered quickly from seed or attracted a diverse and abundant community of beneficial insect species. Floral architecture is a major factor that influences the selection of floral plant resources used by parasitoids (Patt *et al.* 1997). For example, only flowers with completely exposed nectaries can serve as suitable floral host plants for many short-tongued chalcid and ceraphronoid parasitoid wasps, while larger parasitoids such as ichneumonids and braconids are less restricted by the location of the nectaries. Lee and Heimpel (2005) showed that buckwheat had varying impacts on different parasitoid taxa. Wäckers (2004) found that some flowering forbs have a neutral or even repellent effect on parasitoids, implying that simply including flowering plants near crops may not guarantee nectar availability for parasitoids. Gourdine *et al.* (2005) found that some flowering forbs increase parasitoid longevity more than others forbs, although the plant species did not impact parasitism rates. Wanner *et al.* (2006b) found that female parasitoids feeding on the nectar of dill plants increased flight capacity more than feeding on the nectar of oregano plants. Clearly, the floral composition is an important factor influencing the potential effect of non-crop habitats on parasitoid enhancement and pest population suppression.

To date, there is still only limited knowledge and many unresolved issues regarding how best to incorporate floral resources into non-crop areas. The aim of this research was to determine whether a pure stand of flowering plants sown next to soybean fields will increase populations of natural enemies (parasitoids and predators) and ultimately lead to pest suppression. The non-crop areas in the experiments were designed to represent on a smaller scale the grass buffer strips that are planted between crops and adjacent riparian zones as part of the Conservation Reserve Program (CRP). In the U.S., landowners whose agricultural fields border watersheds or bodies of water can receive USDA-Natural Resources Conservation Service (NRCS) funding through CRP to add grass buffers (NRCS 2009a). In Maryland, there are approximately 14,800 total hectares of grass buffer strips (FSA 2010) deployed to reduce agricultural runoff into waterways, spread water flow, and provide wildlife habitat (NRCS 2009b).

Many landowners are adding wildflowers to their CRP grass buffer strips with the notion that this practice will provide food resources to increase pollinators and natural enemies. To promote this practice, NRCS recently revised its recommended list of native wildflower mixes for conservation cover practice standard code 327 to include a wider variety of flowering forbs designed to encourage beneficial insects

and provide floral resources throughout the growing season (NRCS 2009c). NRCS has also added a new mid-contract management practice, which allows eligible participants to receive cost-share to over-seed existing buffer strips with native wildflowers. Despite the widespread use of grass buffer strips and this recent emphasis on adding flowers, little research has been conducted on their effects, especially whether the addition of floral resources will specifically attract parasitoids and predators, which in turn will increase natural enemy density in neighboring crops with adverse consequences for herbivores at varying distances from the bordering refuge.

To address this, I specifically determined: (1) whether the addition of floral resources to the grass buffer strips will increase the density of natural enemies, (2) whether enhanced natural enemy density in buffer strips leads to increased natural enemy density in the neighboring soybean crop, and (3) how far from the buffer strip the natural enemy subsidy extends into the recipient crop.

Methods and Materials

Study System

In this study, I used partridge pea [*Chamaecrista fasciculata* (Michx.) Greene] as an insectary planting sown next to the soybean crop. Partridge pea is a native, annual legume occurring naturally in various non-cropped habitats (Hobson 1972). Because of its nitrogen fixation, prolific seed production, ability to grow in areas unsuitable for other plants, and tendency to form dense stands, partridge pea has long been considered useful for cropland improvement, wildlife habitat, and erosion control (Foote and Jackobs 1966). Seeds of partridge pea are also a major food item for northern bobwhite and other quail species (NRCS 2006), and it is known to be attractive to natural enemy populations (Bugg and Dutcher 1989)**.** In a recent study by Dively (SARE 2008) that compared the relative insectary value of a variety of flowering forbs in a grass buffer, partridge pea was an excellent insectary plant due to its extrafloral nectaries on petioles and leaflets, long bloom period, attractiveness to a diverse assemblage of insects and pollinators, and competitiveness in grass mixes. Plants are densely flowered, each producing up to 60 inflorescences and 300 flowers (Lee and Bazzaz 1982), although each flower produces pollen for one day only but no nectar (Hobson 1972). Also, each leaf petiole has an extrafloral nectary at its base, which continuously produces a small bubble of nectar, both day and night, and throughout the growing season (Kelly 1986). For these reasons, partridge pea is commonly planted in grass mixtures in CRP buffer strips in Maryland (Peter Blank, personal communication, August 4, 2010).

Purple tansy (*Phacelia tanacetifolia*: Hydrophyllaceae) was also tested as a buffer treatment because it has long been considered a valuable insectary plant by agricultural and organic organizations (Hickman and Wratten 1996, Sengonca and

Frings 1988). It senesced quickly in the 2005 experiment, and was not used in the 2006 experiment.

I conducted two separate experiments; one in 2005 examined the effects on natural enemies by several different insectary plantings established next to soybeans in an experimental layout designed to represent on a smaller scale the grass buffer strips typical of the CRP program. The second experiment in 2006 was expanded to a larger spatial scale and specifically determined the natural enemy benefits of pure plantings of partridge pea as buffers bordering soybean fields. Studies focused largely on the enhancement of adult parasitoid populations, though densities of other functional groups were assessed. Both experiments were located at Central Maryland Education and Research Center - Beltsville Facility, Beltsville, Maryland.

2005 Experimental Design

The 2005 experiment involved small plots of full-season soybean (roundup-ready variety 'Hubner-325') planted adjacent to four different buffer treatments on May 11. Each soybean plot measured 16.5 m by 7.5 m (20 rows spaced 35 cm apart) and was flanked on two sides by two buffer strips (each 16.5 m by 4.5 m) of the same type. Both soybean and buffer plots were seeded into a non-tilled field that was planted in corn the previous year. No nitrogen fertilizer was used and standard weed control practices were implemented.

The four buffer treatments were: 1) Purple tansy as an annual, nectar-producing insectary plant; 2) Partridge pea as a leguminous flowering plant with nectar and pollen resources; 3) Mixed buffer consisting of a 50:50 seed combination of purple tansy and partridge pea; and 4) Proso millet (*Panicum miliaceum L.:* Poaceae*)* which served as a structurally similar buffer habitat but lacking floral resources. To establish a strictly structural control with the millet buffer, fruiting terminals prior to blooming were removed to eliminate floral resources. Seeds of partridge pea (Ernst Conservation Seeds, Meadville, PA), purple tansy (S & S Seeds, Carpintaria, CA), and millet (Southern States Cooperative, Easton, MD) were planted by a non-till drill in rows 23 cm apart. Each plot/buffer combination was replicated four times (total of 16 plots), arranged in a randomized complete block design, and separated from other plots in all directions by a 6 m non-crop area (Fig. 1).

The influence of the buffer treatments was assessed by comparing the relative abundance of beneficial insects and other arthropods in soybean fields and adjacent buffers. Given that sampling stations were close to the buffer-crop interface and pure stands of flowering forbs were used, this experiment was most likely to reveal a treatment effect. I predicted that the partridge pea, purple tansy, and mixture of both plants would impact on the soybean arthropod community, particularly beneficial insects that require floral resources, whereas the structural millet buffer would have a neutral effect.

Because 2005 results showed that partridge pea had a significant influence on the arthropod community at a small spatial scale, the 2006 experiment was expanded to field-level scale and focused exclusively on pure plantings of partridge pea as buffers. The experimental layout also added an element of distance to determine how far the buffer effect extended into the crop. The experiment involved 14 contour strips of full-season soybeans (Roundup-ready variety 'Hubner-325'), measuring 27 to 36 m wide and all greater than 150 m long. Soybeans were planted no-till during the period of May 18-25, and weed control and fertility inputs were applied according to recommended practices. The soybean strips were located in five larger field areas, each containing 2, 3 or 4 strips (Fig. 2). Each strip was abutted at one end with a partridge pea buffer plot (6 m by the width of the particular strip). After all soybean strips were established, partridge pea (Ernst Conservation Seeds, Meadville, PA) was drilled non-till in rows 23 cm apart. The other end of each strip without a buffer adjoined to a non-crop grassy area consisting primarily of fescues and orchardgrass. This area was either bridged to another crop field or connected to a woodlot. In each field area, ends with the partridge pea buffer alternated across the multiple strips, which allowed for within and across soybean strip comparisons of buffer effects. In this experiment, I predicted that the abundance of arthropods at the end of the soybean strips next to the partridge pea buffers would different from those at the opposite ends without buffers; and that the impact on the soybean arthropods would be greatest at sampling sites closest to the field edge next to buffers.

Arthropod Sampling Methods

In both experiments, abundance of aerially-active arthropods was measured by yellow sticky cards (Olson products, 7.5 by 12.5 cm) secured to bamboo poles with wooden clothespins at the canopy height of the soybean and buffer plants. In 2005, two sticky cards were placed in each soybean plot: one card was placed in the middle of the plot, while the second one was placed two rows from one of the flanking buffer plots. One card was also placed in the center of each buffer plot. Only one side of each card was exposed and faced the soybean-buffer edge. On July 4, sticky cards were placed at all sampling points and replaced every week thereafter until late summer for a total of nine sampling dates.

In 2006, sticky card sampling was conducted in the partridge pea buffers and at varying distances into the soybean field at opposite ends (with and without buffer). One sticky card was placed in the center of each partridge pea plot, 3 m from the field edge and aligned with a transect of sampling sites within the middle of the adjacent soybean strip. Sticky cards were placed at both ends of the soybean strips at 3, 6, 12, 18, and 24 m from the edge. The exposed side of each card faced the soybean-buffer border. Sampling began on June 28 and continued on a weekly or biweekly basis for a total of eight sampling dates. In both experiments, sticky cards were removed after each sampling period and sealed in clear plastic bags to allow for viewing of captured arthropods. Cards were then brought back to the laboratory, stored in a freezer until

they were processed. Each sticky card was viewed under a stereomicroscope, and arthropods were counted and recorded to the order or family level.

An additional sampling method was used in the 2006 experiment to measure the abundance of epigeal arthropods active on the ground surface. A pitfall trap was installed next to the sticky card at each sampling site. Traps consisted of 355-mL plastic cups containing approximately 60-mL of ethylene glycol and were embedded in the ground so that the top rim of the cup was level with or just below the ground surface. A 30-cm^2 black plastic cover supported by three carriage bolts was placed approximately 2 cm above each trap to prevent disturbance by weather or wildlife. Trap replacement occurred according to the same schedule described above for sticky cards. However, pitfall trap data were recorded on seven sampling dates because one set of traps was flooded (July 6) and discarded due to heavy rains. After retrieval, arthropods captured in pitfall cups were processed in the laboratory by vacuum filtering over organdy cloth to remove the ethylene glycol and excess litter. Samples were then stored in 70% alcohol pending further processing. Samples were later rinsed over fine organdy cloth, which was placed in 150 mm petri dish and viewed under a stereomicroscope. Arthropods were counted and recorded to the order or family level.

Statistical Analysis

The overall diversity and abundance of arthropods were characterized by computing the frequency of occurrence and mean abundance of each taxonomic group per sample unit (sticky card or pitfall trap) for each experiment. These metrics were then used to combine families or orders of taxa into ecological functional categories based on their predominant feeding relations in the community. However, it was not possible for such a broad grouping to reflect all within-family diversity or to capture all stages of a species' life cycle. The functional categories were hymenopteran parasitoids, dipteran parasitoids, predators, herbivores, and saprovores. Parasitoids and predators were considered natural enemies, and herbivores were considered as surrogates for agricultural pests in this system.

For all univariate analyses, assumptions of normality of data and homogeneity of variance were first evaluated using the Shapiro-Wilk *W* test and by examining for nonrandom patterns in residual plots. The square-root transformation was performed prior to analysis to correct for skewness and heterogeneous variances of count data, and back-transformed means were presented for summarization. To avoid pseudo-replication, abundance data for each taxonomic group (family, order, or functional categories) were averaged across sticky cards or pitfall traps within each experimental unit and time period.

A mixed model analysis of variance (Proc Mixed: SAS Institute) was used to test for treatment and interaction effects on selected arthropod groups or combined taxonomic categories. For the 2005 data, buffer types and sampling time were treated as fixed factors, whereas replicates were treated as a random block effect. Due to

differences in sampling dates, main and interaction effects of time and buffer treatments were analyzed separately for the buffer and soybean data. For the 2006 experiment, separate analyses were conducted on abundance data from the soybean strips and buffer. The buffer influence on abundance in the soybean strips was tested for main effects by comparing opposite ends with and without buffer and for interactions with sampling time and distance from the buffer. To test more precisely for spillover effects on natural enemies and other arthropods at the buffer-crop interface, additional analyses were conducted only on data from the 3 m sampling sites in the buffer and at opposite ends of the soybean strips. In all analyses, the repeated measures option was used with the most appropriate covariance structure to correct for correlated data over sampling time. Significant effects among means were separated using Tukey's adjustment for pairwise comparisons ($P \le 0.05$).

2005 Results

Buffer growth characteristics

The proso millet formed a sparsely closed canopy by mid-June and reached about 50 cm in height, comparable to the height of the adjacent soybeans. Though emerging panicles were removed to eliminate available floral resources, millet buffers showed little change in vegetative structure, except for signs of moisture stress and the onset of senescence during late August. Partridge pea formed a lush, closed canopy of alternate compound leaves on erect plants, reaching 30-40 cm in height. Starting in mid-June, petiolar nectaries actively produced nectar each morning, which attracted a wide assortment of insects, and continued to function as extrafloral sources of carbohydrates until late summer. Partridge pea began flowering in early July, peaked at the end of July, but continued blooming through to early September. It remained in good condition throughout the growing season with no visual evidence of moisture stress. Although purple tansy produces an abundant quantity of nectar (Hickman and Wratten 1996, Williams and Christian 1991), it bloomed earlier in the summer and appeared to be lacking floral resources by the first sampling date (July 11). Vegetative cover in the purple tansy buffer was relatively sparse, reaching a height of 25-30 cm, and plants were moisture-stressed and apparently sensitive to hot weather. By mid July, the ferny leaves of purple tansy turned red and the plants senesced, essentially turning this buffer into a structured non-insectary treatment for the remainder of growing season. Because of the poor growth and early decline of purple tansy, the 50:50 mixed buffer was dominated by partridge pea, even early in the season. As a result, the partridge pea and mixed buffers were visually nearly indistinguishable for the majority of the study period.

A total of 93,620 individuals from 98 taxonomic groups within 11 arthropod orders were collected and identified from the sticky cards. Most individuals were identified to the family level.

Of the trophic groups, families of saprovores were the most abundant (46.41%), followed by herbivores (33.76%), parasitoids (16.20%), and predators (3.64%). Several taxonomic groups, such as spiders, ants, and springtails, were not used in the analysis because sticky card captures did not adequately represent their population abundance. Most captures of spiders were dispersing juveniles, while ants and springtails were captured after they moved up the cane pole supporting the sticky card. Overall arthropod abundance dropped dramatically towards the end of the season as both buffer vegetation and soybean plants senesced. For this reason, sticky card data from the last two sampling dates, September 1 and September 8, were not used in the analyses.

Hymenopteran Parasitoids

Egg parasitoids belonging to the families Mymaridae, Scelionidae, and Trichogrammatidae comprised 83.9% of the total captures, while Ceraphronidae, Braconidae, and Eulophidae comprised an additional 12.5% of this functional group. For the first two sampling dates, samples were taken in the soybeans but not in the buffers.

Captures of fairy flies on sticky cards were significantly higher in buffers containing partridge pea ($F_{(3,27.5)} = 32.28$, $p < 0.001$), while these parasitoids were less abundant in soybean plots adjacent to buffers with partridge pea ($F_{(1,20.8)} = 6.53$, $p = 0.0185$) (Fig. 3). Responses of scelionid wasps to the buffer types were different from those of mymarids, in that abundance was greatest in buffers without partridge pea ($F_{(3,19.2)} = 10.77$, $p = 0.0002$) and not significantly different within soybean plots with respect to the adjacent buffer type (Fig. 4). Trichogrammatid wasps responded to a significant date by treatment interaction effect in the buffers ($F_{(12,40.5)} = 5.38$, $p < 0.001$), with abundance highest in millet at the start of the season, and then highest in buffers containing partridge pea at the end of the season. No significant differences in trichogrammatid abundance within soybean plots were observed with respect to the adjacent buffer type (Fig. 5). Ceraphronid abundance was significantly higher in buffers containing millet compared to levels of captures in the other buffer types ($F_{(3,28)} = 16.53$, $p < 0.001$), which were not significantly different. Relative abundance followed the same trend in the soybean plots, and abundance was significantly higher in soybean plots adjacent to buffers lacking partridge pea ($F_{(1,27.1)} = 6.51$, $p = 0.0167$) (Fig. 6).

Dipteran Parasitoids

Of the many families of dipterans captured on sticky cards in both habitats, the combined group of Sarcophagidae and its sister family Tachinidae averaged 9.4 ±

1.10 and 4.4 ± .55 flies per card in the buffers and soybean plots, respectively. No attempts were made to separate these families due to their similar morphology and inability to manipulate insects embedded on the sticky cards. Many species of sarcophagids inhabiting crop fields are parasitoids (Herrick 1921; Kelly 1914; Danyk *et al*. 2000), therefore this combined group was assumed to be parasitoids which could benefit by floral resources. Fig. 7 shows that the relative abundance of parasitic flies was significantly higher in buffers with partridge pea, especially during late August (interaction effect: $F_{(12,37.1)} = 2.21$, $p = 0.032$). Likewise, soybean plots next to buffers with partridge pea were inhabited by more tachinids and sarcophagids than plots next to buffers without partridge pea (contrast effect: $F_{(1,23.6)} = 4.19$, $p = 0.052$).

Arthropod predators

Overall captures of arthropod predators averaged 7.6 ± .45 and 3.0 ± .24 per sticky card in the buffers and soybean plots, respectively. Dolichopodidae (long-legged flies), Anthocoridae (*Orius* spp, minute pirate bug), and Coccinelidae (lady beetles) comprised 78.9% of total captures, while Geocoridae (big-eyed bugs), Therevidae (stiletto flies), and Lampyridae (fireflies) comprised an additional 10.3%. Pooled over all predators, there were no interaction effects but populations changed significantly over time in the soybean ($F_{(6,52.6)} = 11.20$, $p < 0.001$) and buffer plots ($F_{(4,41.3)} = 15.67$, $p < 0.001$). Predator populations peaked in mid-July in soybean, particularly in plots adjacent to partridge pea and millet buffers (Fig. 8), while populations increased gradually throughout the growing season in the buffer plots.

As shown in Fig. 8, overall abundance of predators was significantly higher in the purple tansy and millet buffers than in the partridge pea or mixed partridge pea/purple tansy buffers ($F_{(3,20.6)} = 11.90$, $p < 0.001$). Main effect means were 5.0 ± .62, 6.8 ± .78, 8.5 ± .87, and 10.3 ± .88 for partridge pea, mixed partridge pea/purple tansy, purple tansy and millet, respectively. Of the predators, dolichopodid flies and coccinelids comprised 59% of the predator community and were significantly more abundant in the purple tansy and millet buffers. In the soybean plots, there were no differences in abundance of predators with respect to the type of adjacent buffers. Main effect means were 3.2 ± .54, 3.0 ± .41, 2.3 ± .32, and 3.4 ± .60 predators per sticky card in soybeans adjacent to partridge pea, mixed partridge pea/purple tansy, purple tansy and millet, respectively.

Arthropod Herbivores

Small, aerially-active sucking insects were the predominate herbivores captured on sticky cards. Overall numbers of individuals averaged 79.2 ± 4.13 and 45.4 ± 3.28 insects per card in the buffers and soybean plots, respectively. Thysanopterans and hemipterans (mainly leafhoppers, planthoppers and plant bugs) comprised 43.7 and 42.3% of the herbivore group, respectively; while aphids, lepidopteran adults and small larvae, and grasshoppers made up an additional 3.9%. Relative frequency and composition of herbivore taxa were similar in the buffer and

crop habitats, except that thrips were much more abundant in soybean compared to the buffers.

There was a significant interaction effect of sampling date and buffer type on herbivore abundance in the buffers ($F_{(12,41.7)} = 3.42$, $p = 0.002$). As shown in Fig. 9, relative abundances among buffers changed after the first sampling date (July 25), and from that point forward, abundances were consistently higher in the millet and purple tansy buffers than in either of the buffers containing partridge pea. Because there was no directional change in interaction differences among means, the main effect for buffer type was highly significant ($F_{(3,13)} = 11.90$, $p = 0.0005$), with means of 54.0 ± 5.9, 59.8 ± 4.0, 115.1 ± 7.8, and 88.8 ± 6.62 herbivores captured per card for partridge pea, mixed partridge pea/purple tansy, purple tansy, and millet, respectively.

In soybean plots, the sampling date effect was significant ($F_{(6,52.3)} = 29.9$, $p < 0.001$) indicating a greater abundance of herbivore taxa, mainly thrips and hoppers, during late July and the again in late August (Fig. 9). However, there were no significant main or interaction effects on herbivore abundance with respect to the adjacent buffer type. Main effect means were 47.5 ± 7.70, 39.5 ± 5.13, 45.0 ± 6.00, and 49.7 ± 7.31 for partridge pea, mixed partridge pea/purple tansy, purple tansy and millet, respectively.

Arthropod saprovores

Numerous dipteran and coleopteran families comprised the saprovore community, of which individuals averaged 143.2 ± 8.33 and 55.7 ± 4.01 per sticky card in the buffers and soybean plots, respectively. Because of their distinctive wing venation and body characteristics, flies in the families Chloropidae, Otitidae, and Phoridae were recorded separately, whereas all other dipteran saprovores were arbitrarily pooled into one group. The dipterans comprised 95.8% of the saprovores, followed by fungivorous beetles of various families and psocids.

There were no interaction effects of sampling date and buffer type for both habitats, though saprovore abundance significantly changed over time in the soybean plots ($F_{(6,50.3)} = 13.1$, $p < 0.001$) but was not influenced by the adjacent buffers (Fig. 10). Average captures in soybean were 61.5 ± 10.87, 52.6 ± 6.52, 47.1 ± 6.70, and 61.5 ± 7.80 insects per card for partridge pea, mixed partridge pea/purple tansy, purple tansy and millet, respectively. For buffers, the number of saprovores captured in the purple tansy was significantly lower than numbers captured in other buffer types ($F_{(3,18.4)} = 3.72$, $p = 0.030$). Saprovores were most abundant in partridge pea (185.4 ± 19.30 per card) compared to captures in millet (146.6 ± 13.20 per card), the mixed buffer (142.9 ± 18.35 per card), and purple tansy (95.7 ± 6.62 per card), but differences were not significant. However, the contrast test comparing buffers with and without partridge pea showed a significant difference ($F_{(1,18.4)} = 4.79$, $p = 0.042$).

2006 Results

Buffer Growth Characteristics

The drilled seedlings of partridge pea in most buffers rapidly formed a lush, closed canopy of erect plants by the end of June, reaching 30-40 cm in height. Petiolar nectaries were actively producing nectar each day and continued to attract many taxa of insects until late August. The plants bloomed continuously from early July through August and showed little evidence of stress during the growing season. The border areas at the opposite end of the soybean strips consisted primarily of grass borders that were mowed once during late June.

Overall Diversity of the Aerial Community

A total of 248,115 individuals from 97 taxonomic groups within 11 arthropod orders were captured and identified from the sticky cards. Most individuals were identified to the family level. Saprovores were the most abundant (46.0%), followed by herbivores (41.5%), parasitoids (10.3%), and predators (2.2%). Consistent with the 2005 study, spiders, ants, and springtails were deleted from the analysis because their abundance is poorly estimated by sticky card sampling. Overall arthropod abundance dropped dramatically towards the end of the season as both buffer and soybean plants began to senesce. Data from the last sampling period ending on September 5 were not included in the analyses because captures were very low.

Hymenopteran parasitoids captured with sticky cards

Egg parasitoids belonging to the families Mymaridae, Trichogrammatidae, and Scelionidae comprised 84.3% of the total captures in order of abundance, while Ceraphronidae, Braconidae, and Eulophidae comprised an additional 10.3%. The three most abundant families of parasitoids responded differently.

Mymarids made up 49.3, 32.4, and 34.3% of all hymenopteran parasitoids and averaged 10.0 ± 1.15, $4.7 \pm .22$ and $5.0 \pm .22$ per sticky card in the buffers, soybean strip adjacent to buffers, and at the opposite end of the strips without buffers, respectively. The partridge pea buffer attracted significantly higher numbers of fairy flies but did not influence fairy fly abundance in soybeans as evident by the non-significant difference between opposite ends of the strips (Fig. 11). Moreover, there was no treatment by distance effect suggesting evidence of increased activity at the 3m sampling site at the buffer end of the soybean strips. Trichogrammatid wasps were less abundant in the buffers compared to captures in the soybeans. Sticky card captures averaged $4.1 \pm .44$, $5.2 \pm .23$ and $4.8 \pm .22$ per sticky card in the buffers, soybean strip adjacent to buffers, and at the opposite end of the strips without buffers, respectively. Differences in trichogrammatid activity changed over time between ends of the soybean strips ($F_{(6,581)} = 2.52$, $p = 0.021$) but overall activity was not affected by the presence of the buffer (Fig. 12). These parasitoid wasps exhibited a significant

edge effect at both ends of the soybean strips ($F_{(4,196)} = 2.69$, p = 0.032). Scelionid wasp captures averaged 2.1 ± .19, 2.4 ± .10 and 2.5 ± .10 per sticky card in the buffers, soybean strip adjacent to buffers, and at the opposite end of the strips without buffers, respectively. Scelionid activity in the soybean strips was also higher than levels in the buffer during July but there was no evidence of any enhancement of activity at the buffer end of the soybean strips (Fig. 13). The sampling date by distance interaction was the only significant effect, indicating that scelionids were lowest at sites closest to the field edge during July but then higher at the field edge later in the sampling period ($F_{(24,563)} = 2.29$, $p = 0.0005$).

Sarcophagid and tachinid flies

Sarcophagid and tachinid flies were again not recorded to the family level because of the difficulty in identifying flies on sticky cards. Overall captures averaged 20.3 ± 1.31, 8.8 ± .42 and 6.9 ± .29 per sticky card in the buffers, soybean strip adjacent to buffers, and at the opposite end of the strips without buffers, respectively. These flies were very active in the canopy of partridge pea, which apparently had an influence of the population in the adjacent soybean strip. Abundance was significantly higher at soybean sites adjacent to buffers compared to the opposite end of the strips without buffers, except at the first and last sampling dates (treatment by date effect: $F_{(6,604)} = 2.75$, $p = 0.012$) (Fig. 14). Furthermore, an analysis of the 3 m data (including the buffer sites) showed a significant treatment effect ($F_{(2,72.3)} = 35.84$, $p < 0.001$), with abundance highest in buffers and at the soybean field edge next to the buffer. As shown by the bar graph in Fig. 14, these flies were also more abundant at sampling sites near the soybean field edge ($F_{(4,225)} = 4.56$, $p = 0.002$), particularly at the strip ends next to the buffer.

Arthropod Predators

Overall numbers of predators captured per sticky card averaged 11.5 ± 1.1, 4.1 ± .16 and 4.9 ± .18 in the buffers, soybean strip adjacent to buffers, and at the opposite end of the strips without buffers, respectively. Long-legged flies (Dolichopodidae), minute pirate bugs (Anthocoridae), and big-eyed bugs (Geocoridae) comprised 81.4% of total captures of predatory arthropods, while Cantharidae, Lampyridae, and Coccinelidae comprised an additional 11.6%. These predatory taxa were significantly more active in the soybean canopy at the end of strips without buffers ($F_{(1,231)} = 7.44$, $p = 0.007$) (Fig. 15). This response was largely attributed to the activity of long-legged flies which comprised about 60% of all predators captured. These predaceous flies were highly attracted to the partridge pea but significantly less abundant at soybean sites next to the buffers compared to captures at the opposite ends without buffers ($F_{(1,227)} = 23.7$, $p < .0001$). Furthermore, there was a significant date by distance interaction effect ($F_{(24,602)} = 1.83$, $p = 0.01$) indicating that differences in predator activity across the transect of sampling sites changed with sampling date. Predator abundance in the soybean strips was slightly

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higher at sites further away from the field edge during the earlier sampling dates, but then showed a significant edge effect during late August.

Arthropod herbivores

Captures per sticky card of arthropod herbivores averaged 108.2 ± 6.64, 96.3 ± 2.49 and 96.4 ± 2.60 in the buffers, soybean strip adjacent to buffers, and at the opposite end of the strips without buffers, respectively. Thrips (Thysanoptera), leafhoppers, treehoppers, froghoppers, and planthoppers comprised over 95% of the herbivores captured on sticky cards. Herbivores were slightly more abundant in the partridge pea buffers but differences compared to activity in soybeans were not statistically significant. Populations at all sites varied consistently over time but there were no significant main or interaction effects suggesting possible influence by the buffer (Fig. 16).

Arthropod saprovores

Grass flies (Chloropidae) and several other dipterans comprised 97.6% of the saprovores captured on sticky cards. Number of arthropod saprovores per sticky card averaged 363.7 ± 25.37, 96.3 ± 3.76 and 68.4 ± 3.04 in the buffers, soybean strip adjacent to buffers, and at the opposite end of the strips without buffers, respectively. Dipterans were highly attracted to the partridge pea buffers which also apparently augmented fly activity in the soybean crop adjacent to the buffers (Fig. 17). A significant treatment by distance effect ($F_{(4,212)}$ = 3.92, p = .0043) revealed a strong edge effect in the soybean crop adjacent to buffers, whereas abundance remained relatively even across sampling sites at the end without (bar chart in Fig. 17). A significant date by buffer interaction ($F_{(6,653)}$ = 3.55, p = .0018) also indicated that numbers of saprovores in the crop adjacent to buffers was greatest during early August and then declined toward the end of sampling period as fly abundance dropped off in the buffers.

Overall diversity of the epigeal community

A total of 56,296 arthropods from 55 taxonomic groups were collected and identified from pitfall traps. Most individuals were identified to the family level. Saprovores were the most abundant (54.5% of total captures), followed by predators (38.4%), parasitoids (4.8%), and herbivores (2.3%). Overall activity of epigeal arthropods peaked on August 8 and steadily declined during the remaining sampling period. In general, pitfall captures of epigeal arthropods in the partridge pea buffers were about 50% greater than captures in soybeans. However, the frequencies of occurrence and rankings of the top 12 most abundant taxa were closely similar across all sampling sites.

Arthropod predators captured in pitfall traps

Pitfall captures of predators averaged 33.2 ± 3.25, 20.8 ± 1.83, and 22.4 ± 1.39 per trap in the buffers, soybean strip adjacent to buffers, and at the opposite end of the strips without buffers, respectively. Of the predator taxa, ants (Formicidae), spiders (Aranae), soldier beetle larvae (Cantharidae), rove beetle adults and larvae (Staphylinidae), and ground beetle adults and larvae (Carabidae) comprised 40.9, 30.0, 11.0, 9.3, and 6.7 % of total captures, respectively. Captures of predators as a trophic group revealed no significant main or interaction effects with respect to the presence of buffer, except for sampling date ($F_{(5,514)} = 10.99$, $p < 0.001$) (Fig. 18). Of the five predator taxa listed above, only Formicidae displayed a significant treatment effect ($F_{(1,226)} = 9.25$, $p = 0.003$), indicating that ant activity was significantly lower at soybean sites adjacent to the buffers on all sampling dates.

Saprovores captured in pitfall traps

Crickets (Gryllidae), flies (several families), and fungivorous beetles comprised the majority of saprovores and averaged 44.2 ± 4.92, 33.0 ± 1.57 and 30.6 ± 1.42 per trap in the buffers, soybean strip adjacent to buffers, and at the opposite end of the strips without buffers, respectively. Numbers of saprovores in the buffers was significantly higher than captures in the soybean crop ($F_{(2,59.8)} = 5.76$, $p = 0.005$), based on an analysis of data at the 3m sites closest to the soybean-buffer interface. However, the presence of partridge pea and the distance from the field edge had no influence on saprovore abundance in the adjacent soybean crop.

Discussion

Buffer plantings of partridge pea clearly attracted many taxonomic groups of natural enemies. The lush, closed canopy provided shelter and a continuous supply of pollen from flowers and nectar from petiolar nectaries from July through to early September. Although purple tansy is commonly used as an insectary planting to provide floral nectar for aphidophagous syrphid flies and adult parasitoids (Sengonca and Frings 1988), it did not enhance natural enemies in the 2005 study. This cool-season annual matured in late June and senesced rapidly due to the hot, dry growing conditions. In hindsight, it was not a suitable buffer treatment to compare with partridge pea, at least within the time period of the 2005 study. In the 2005 experiment, overall sticky card captures of hymenopteran and dipteran parasitoids were 72.7% higher in buffers containing partridge pea compared to the other buffer types. Similarly, communities of all beneficial arthropods captured by sticky card and pitfall traps in 2006 were significantly 79.8% to 72.3 % higher, respectively, in the partridge pea buffers compared to communities in the soybean crop. However, buffer effects on populations of parasitoids and predators in the neighboring crop were mixed in both experiments depending on the particular functional group and specific family of arthropods.

A primary aim of this study was to determine if the flowering buffers enhance adult parasitoid populations in the adjacent soybean crop. As a functional group, the 2006 results showed evidence of higher populations closer to the buffer-soybean crop interface but overall populations of parasitoids in the crop in both experiments were not enhanced by the presence of partridge pea. However, specific families of parasitoids showed differential responses in the crop and buffer habitats. In both experiments, dipteran parasitoids were highly attracted to the partridge pea which acted as a source and apparently led to increased fly abundance in the adjacent soybeans. In 2006, this source effect was accentuated at the field edge next to buffers, suggesting that the higher numbers of parasitic flies spilled over to the neighboring soybeans but this effect extended only a short distance into the crop. Most of the dipteran parasitoids found on sticky cards were tachinids or sarcophagids. The larvae of tachinid flies are important parasitoids of many lepidopteran, coleopteran, and heteropteran pests in agricultural systems (Grenier 1988). While generally thought of as flesh-eating flies, many species of sarcophagids in crop fields are also beneficial parasitoids (Herrick 1921; Kelly 1914; Danyk et al. 2000).

Mymarid wasps were by far the most common parasitoids captured on sticky cards and were significantly more numerous in partridge pea compared to levels in soybean. These tiny wasps parasitize hemipteran, coleopteran, orthopteran, and dipteran eggs in concealed sites in plant tissues or soil (Gibson 1993, Loomans 2003). In particular, mymarids are important biocontrol agents of economically important leafhopper pests (Yang et al. 2002, Pilkington et al. 2005). Adult mymarids, like other hymenopteran parasitoids, feed on a carbohydrate energy source, such as nectar or honeydew, to fulfill their dietary requirements (Jervis and Kidd 1986; Jervis et al.

1993). In the 2005 study, mymarids reached levels in buffers with partridge pea that were four-fold higher than those in the soybean plots. Yet, there were significantly lower levels of mymarids in the soybean plots next to these buffers, suggesting a possible sink effect. It is possible that the high attractiveness of the partridge pea with an abundant source of floral resources as well as hosts lured these wasps from the neighboring soybean plots, thus decreasing their abundance. With rare exceptions (Olson and Wäckers 2007), most studies on the effect of flowers on abundance of parasitoids in neighboring crop fields have shown an either neutral or positive effect. Furthermore, Bianchi *et al.* (2006) suggested that non-crop habitats could only act as sinks if the natural enemies had a year-round preference for the non-crop habitat over the crop. Mymarids were also highly attracted to the partridge pea in 2006, but abundance in the soybean strips, even at 3m from the field edge next to the buffer, was not affected by the presence of partridge pea. Nonetheless, the 2005 results suggest the possibility that a pure stand of an attractive insectary plant could provide all the hosts and floral resources for parasitoids to successfully survive and reproduce, and thus no incentive for them to leave.

Partridge pea was much less preferred by the other major families of hymenopteran parasitoids (Trichogrammatidae, Scelionidae, Ceraphronidae) and had no apparent effect on the relative abundances of these parasitoids in the soybean crop during both years. In 2005, captures of trichogrammatids were significantly higher in the millet buffers during most of the sampling period but this effect did not extend into the soybean plots. Long *et al*. (1998) showed that trichogrammatids took advantage of floral resources in a non-crop area but did not migrate into neighboring wheat fields, while braconids and other beneficial insects did. Since this buffer treatment did not provide floral resources, the wasps were probably attracted to the habitat structure and available hosts in the millet. Trichogrammatids are all egg parasitoids of holometabolus orders as well as Homoptera, Heteroptera, Orthoptera, and Thysanoptera (Gibson 1993). As the season progressed, however, trichogrammatid abundance decreased in the millet and increased in buffers containing partridge pea and in the adjacent soybean plots. The exodus was probably due to increasing drought stress and developing senescence in the millet. This was also a limiting factor in the purple tansy buffers which had the least abundance of trichogrammatids.

Scelionid and ceraphronid wasps preferred the millet and purple tansy buffers to those with partridge pea, but abundance in soybean plots adjacent to buffers was not enhanced. Scelinoids are solitary endoparasitoids of a very diverse host range of insect and spider eggs. As adults they prefer open, sunny habitats (Masner 1983, Masner 1993a, Allaby 1999), such as the more open canopy provided by the millet and purple tansy buffers. Ceraphronid wasps are endoparasitoids of Thysanoptera, Lepidoptera, Neuroptera, Cecidomyiidae (Diptera), and puparia of higher Diptera (Masner 1993b). Since senesced millet and purple tansy provided little if any floral resources, these results demonstrate that plants need not necessarily have floral resources in order to attract natural enemies and encourage their dispersal into neighboring crop fields (Landis *et al*. 2005).

Despite the attractiveness of the buffers containing partridge pea, arthropod predators were 65% more abundant in the millet and purple tansy buffers in the 2005 study. This response was mainly attributed to the activity of long-legged flies which comprised about 60% of all canopy-dwelling predators captured. Dolichopodids are important natural enemies of insect pests in crop systems, where they consume small, soft-bodied arthropods, particularly other dipterans, aphids, spider mites, larvae of small insects, and thrips (Ulrich 2005). These flies hover to search for prey (Zimmer *et al*. 2003); thus, the open canopy of the millet and purple tansy buffers probably provided a more favorable habitat for their ecology and behavior in contrast to the dense canopy of partridge pea. Abundance of long-legged flies in the soybean plots in 2005 was not affected by buffer type.

In 2006, dolichopodids were also the predominant predators captured on sticky cards, followed by minute pirate bugs. Overall numbers of predators were 2-3 times higher in the partridge pea buffers compared to levels in the soybean strips, yet predator abundance was significantly higher at the opposite end of the strips without partridge pea. Moreover, predator activity across the transect of sampling sites was skewed toward the field edge next to the buffer, suggesting that partridge pea acted as a sink by attracting predators in response to higher levels of available prey or shelter afforded by the dense canopy of the buffer. For example, certain lady beetles and minute pirate bugs *Orius insidiosus* (Say) feed on pollen as a supplementary protein source,and thus could be attracted to partridge pea for pollen which was not available in soybeans.

Of the ground-dwelling predators captured by pitfall traps, ants were the predominant group and captured in higher numbers in the partridge pea buffers than in the soybean strips. It is likely that ants were taking advantage of the extra-floral nectaries as well as responding to the higher numbers of herbivores and saprovores in the partridge pea. However, captures were significantly lower at soybean sites adjacent to the buffers on all sampling dates, suggesting that the buffer acted as a sink drawing ants out the soybeans. Populations of other ground-dwelling predators, consisting mainly of spiders, rove beetles, soldier beetles and ground beetles, showed a definite preference for partridge pea over soybeans but levels in soybeans were not affected by the presence of the buffer.

Other functional groups beside parasitoids and predators were differentially affected by the presence of the buffers. In both years, buffers containing partridge pea harbored significantly more canopy-dwelling saprovores, of which over 95% were dipterans, predominantly chloropids. None of the buffer types affected the levels of these saprovores in the 2005 study. However, partridge pea acted as a source for saprovores in 2006 as evidenced by significantly higher numbers in soybean sites adjacent to the buffer and at sampling sites closest to the soybean-buffer interface. Source effect was not detectable beyond 6m. Partridge pea also harbored more epigeal saprovores but did not influence saprovore abundance in the adjacent soybean crop. Likewise, the higher herbivore abundance in buffers containing partridge pea in both years did not extend into the soybean crop. Generally, the abundance and

diversity of natural enemies across habitats are directly influenced by the availability of suitable prey and host organisms. However, in this study, there was no evidence that differences in the numbers of herbivores and saprovores might explain why certain buffers and sampling sites in the soybean crop had higher or lower abundance of beneficial arthropods.

In summary, pure stands of partridge pea were highly attractive to many beneficial arthropods but populations in the neighboring soybean crop were largely unaffected. Partridge pea was a source for canopy-dwelling dipteran parasitoids and saprovores, but acted as a sink for canopy-dwelling mymarids, canopy-dwelling predators and ground-dwelling ants, and had a neutral effect on all other functional groups. However, these effects did not extend far into the soybean crop and were generally not discernible beyond 6m. Results suggest that a pure stand of an attractive source of floral resources in a bordering non-crop area may not be desirable for enhancing conservation biological control. For this reason, the species of wildflower and desired natural enemy should be taken into consideration before determining the mix of plant species to include in a buffer strip.

Figure 1. Randomized complete block design of the 2005 experiment with four replicates of four buffer treatments: partridge pea (PP), purple tansy (PT), mixture of both (MIX), and millet as a structural control buffer. Each soybean plot (17 m x 9 m) was flanked by two buffer strips (17 m x 4.5 m).

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Figure 2. Aerial view layout of 14 contour strips of full-season soybeans and adjacent partridge pea buffers in 2006 experiment. Each strip measured 27 to 36 m wide and greater than 150 m long, and was abutted at one end with a partridge pea buffer plot (6 m by the width of the particular strip) (indicated by black polygons). The opposite end of each strip without a buffer adjoined to a non-cropped grassy area. Adjacent soybean strips alternated end positions of the buffer.

Figure 3. Mean number (±SEM) of mymarids captured by sticky cards in four types of buffer plots bordering soybeans. Main and interaction effects were analyzed separately for the buffer and soybean data. Buffer effect was significant in buffer plots ($F_{(3,27.5)} = 32.28$, $p < 0.001$). Contrast test revealed that abundance was lower in soybean plots next to buffers containing partridge pea ($F_{(1,20.8)} = 6.53$, $p = 0.019$). 2005.
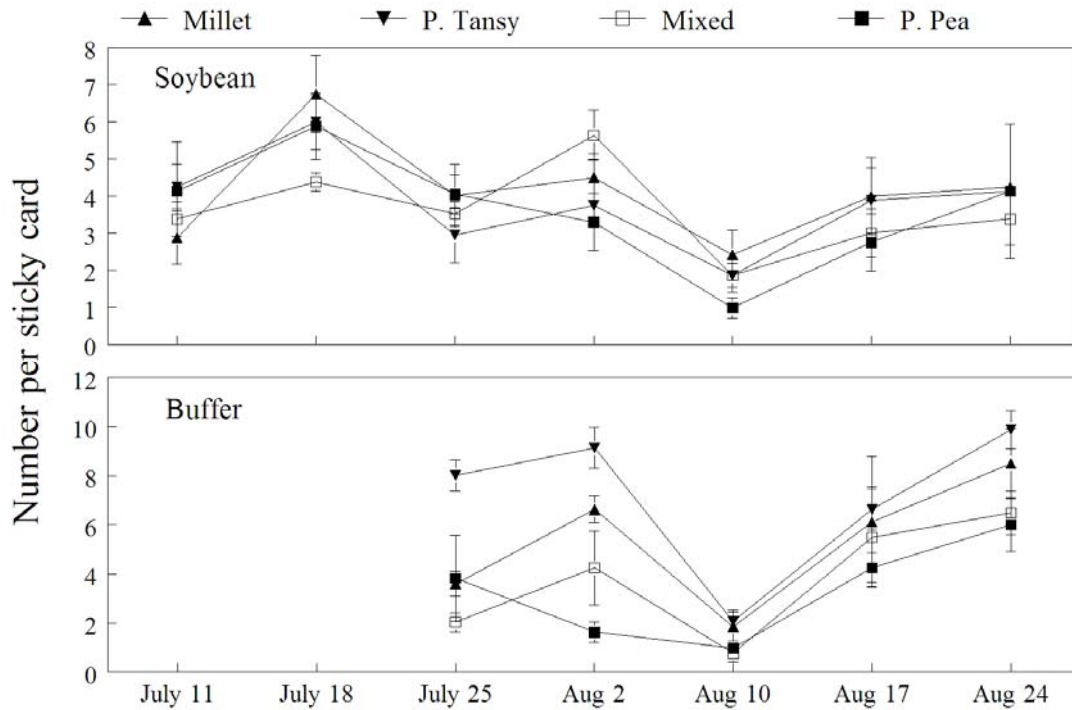
Figure 4. Mean number (±SEM) of scelionids captured by sticky cards in four types of buffer plots bordering soybeans. Main and interaction effects were analyzed separately for the buffer and soybean data. Buffer effect was significant in buffer plots ($F_{(3,19.2)} = 10.77$, $p = 0.002$). Buffer treatment did not have a significant impact on abundance in neighboring soybean plots. 2005.
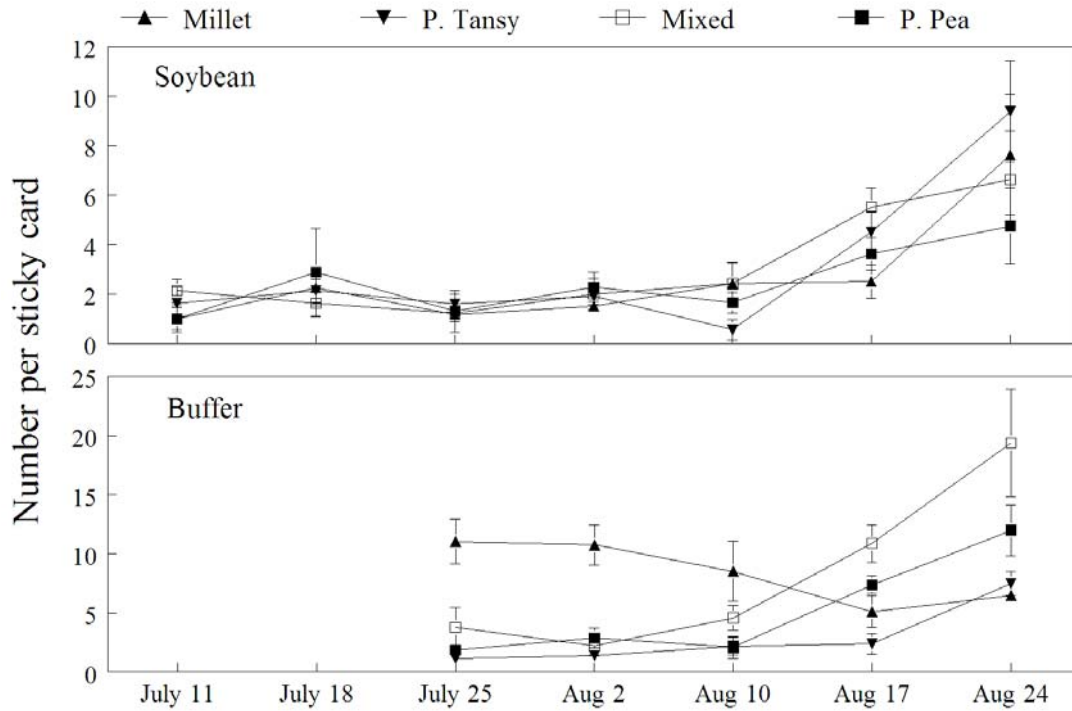
Figure 5. Mean number (±SEM) of trichogrammatids captured by sticky cards in four types of buffer plots bordering soybeans. Main and interaction effects were analyzed separately for the buffer and soybean data. There was a significant date by treatment interaction effect in the buffers ($F_{(12,40.5)} = 5.38$, $p < 0.001$). Buffer treatment had no significant impact on abundance in neighboring soybean plots. 2005.
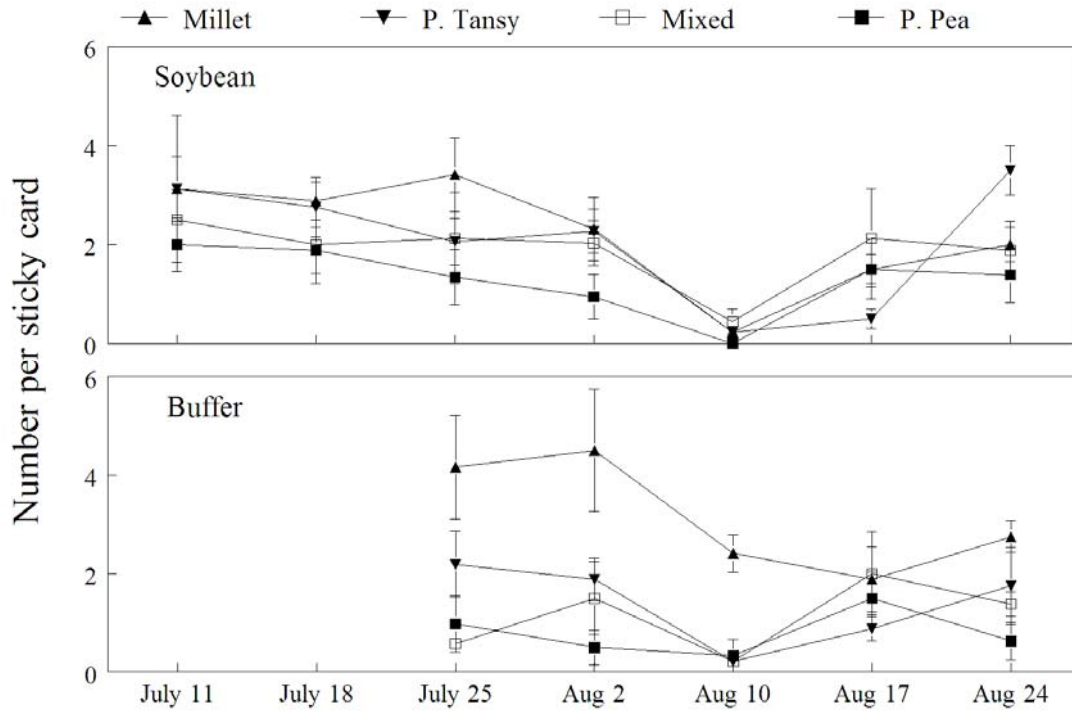
Figure 6. Mean number (±SEM) of ceraphronids captured by sticky cards in four types of buffer plots bordering soybeans. Main and interaction effects were analyzed separately for the buffer and soybean data. Buffer treatment was significant types ($F_{(3,28)}$ = 16.53, $p < 0.001$). Contrast test demonstrated abundance was significantly higher in soybean plots adjacent to buffers lacking partridge pea ($F_{(1,27.1)}$ = 6.51, $p = 0.0167$). 2005.
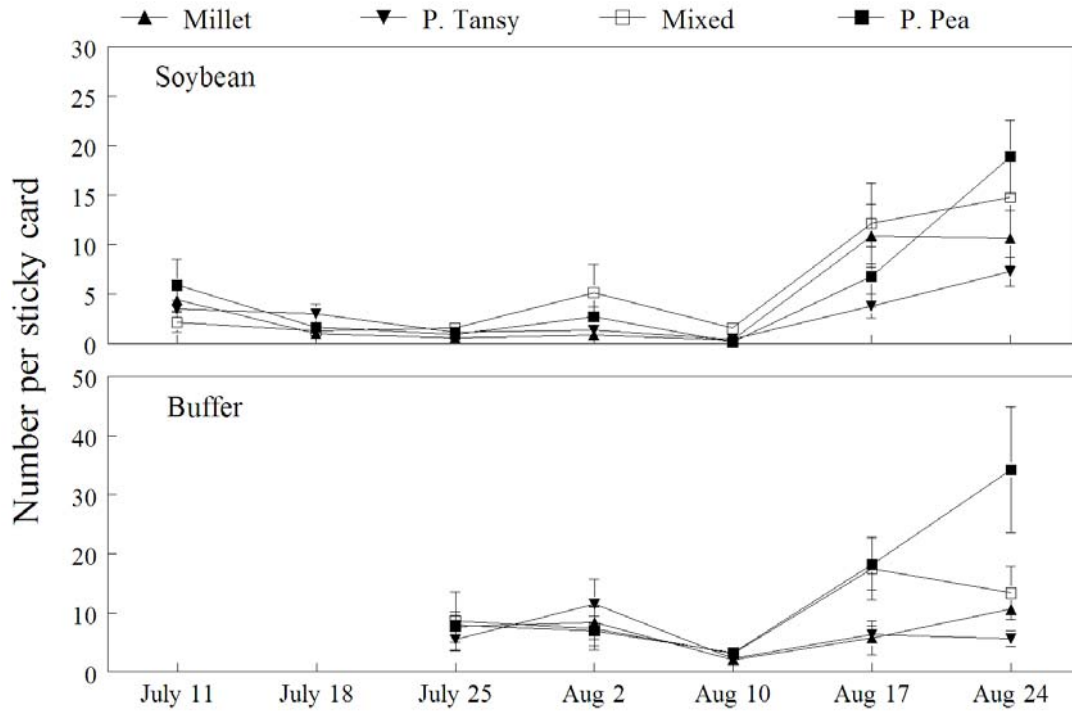
Figure 7. Mean number (±SEM) of dipteran parasitoids captured by sticky cards in four types of buffer plots bordering soybeans. Main and interaction effects were analyzed separately for the buffer and soybean data. Abundance was higher during late August in buffers with partridge pea (interaction effect; $F_{(12,37.1)} = 2.21$, $p = 0.032$). Abundance was higher in soybean plots next to buffers with partridge pea (contrast effect: $F_{(1,23.6)} = 4.19$, $p = 0.052$). 2005.
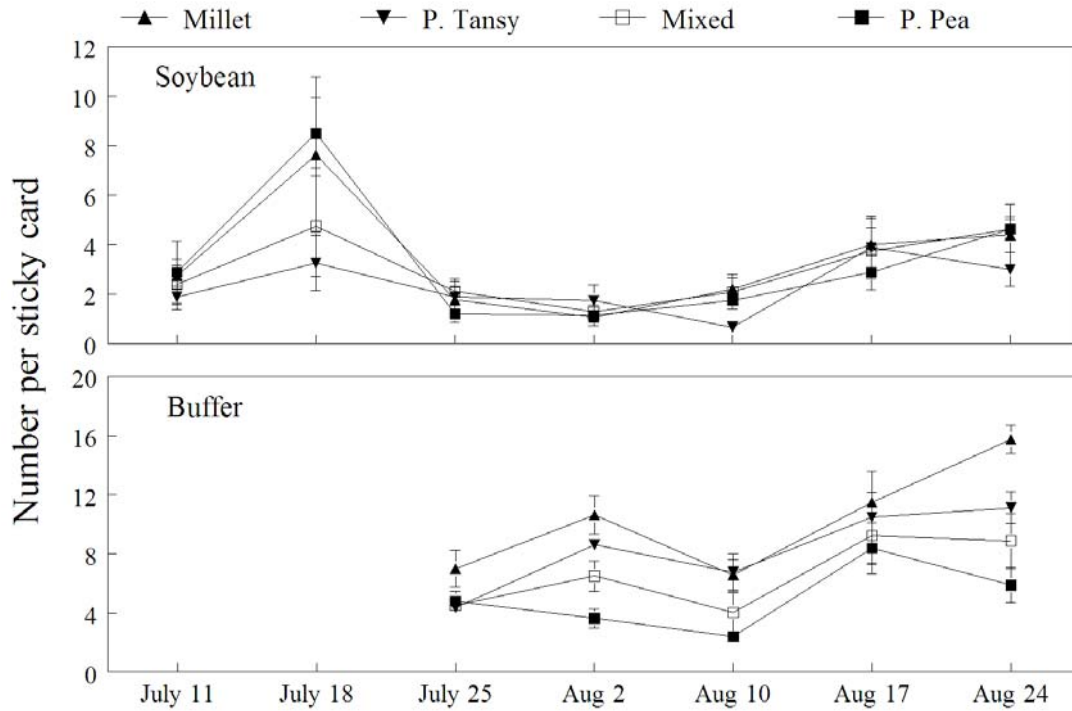
Figure 8. Mean number (±SEM) of arthropod predators captured by sticky cards in four types of buffer plots bordering soybeans. Main and interaction effects were analyzed separately for the buffer and soybean data. Abundance was higher in buffers without partridge pea ($F_{(3,20.6)} = 11.90$, $p < 0.001$). Buffer treatment had no significant impact on abundance in neighboring soybean plots. 2005.
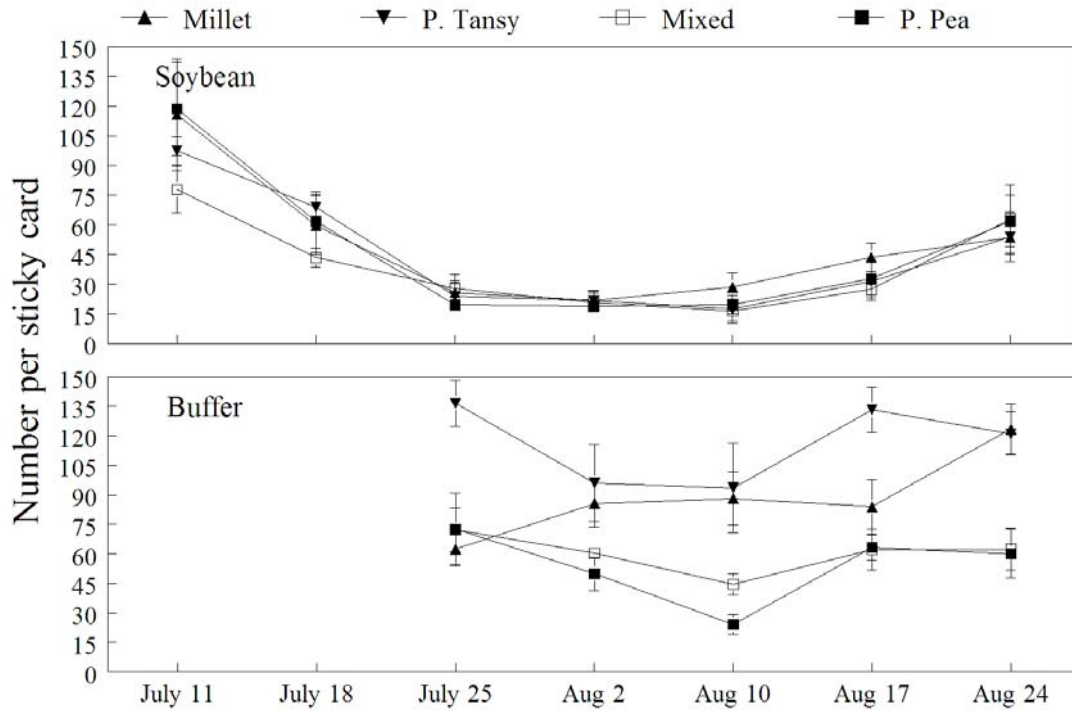
Figure 9. Mean number (±SEM) of arthropod herbivores captured by sticky cards in four types of buffer plots bordering soybeans. Main and interaction effects were analyzed separately for the buffer and soybean data. There was a significant interaction effect of sampling date and buffer type in the buffers ($F_{(12,41.7)} = 3.42$, $p = 0.002$), with abundance higher in buffers without partridge pea ($F_{(3,13)} = 11.90$, $p = 0.0005$). Buffer treatment had no significant impact on abundance in neighboring soybean plots. 2005.
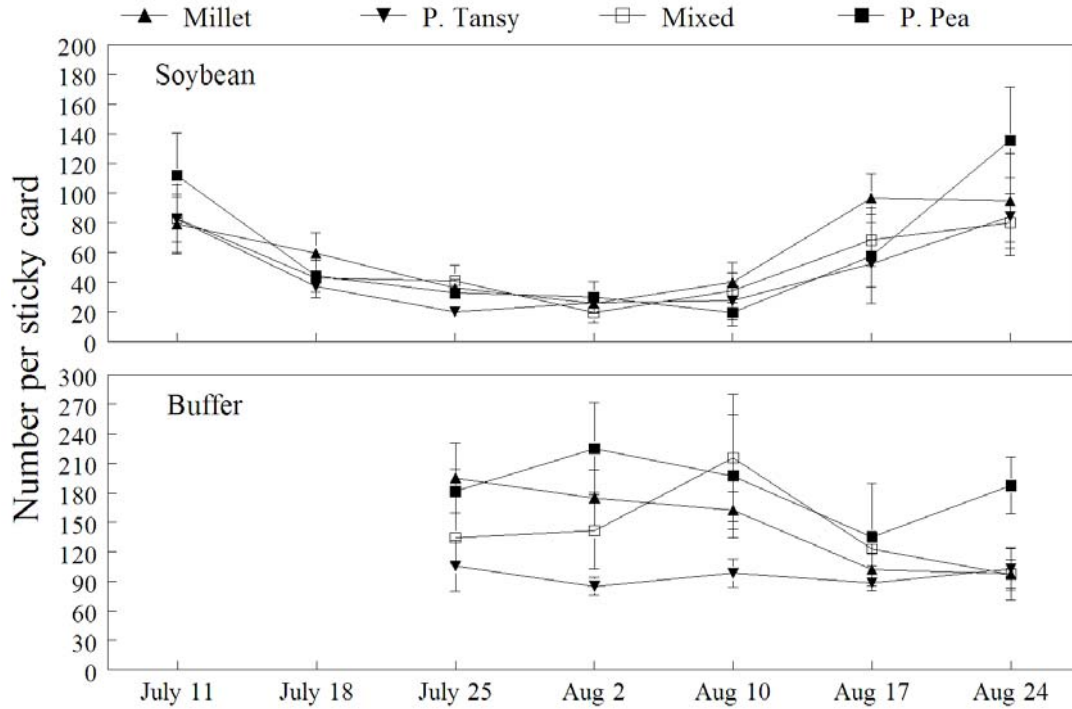
Figure 10. Mean number (±SEM) of arthropod saprovores captured by sticky cards in four types of buffer plots bordering soybeans. Main and interaction effects were analyzed separately for the buffer and soybean data. Abundance was significantly lower in purple tansy ($F_{(3,18.4)}$ = 3.72, p = 0.030). Contrast test revealed that abundance was higher in buffers containing partridge pea ($F_{(1,18.4)}$ = 4.79, p = 0.042). Buffer treatment had no significant impact on abundance in neighboring soybean plots. 2005.
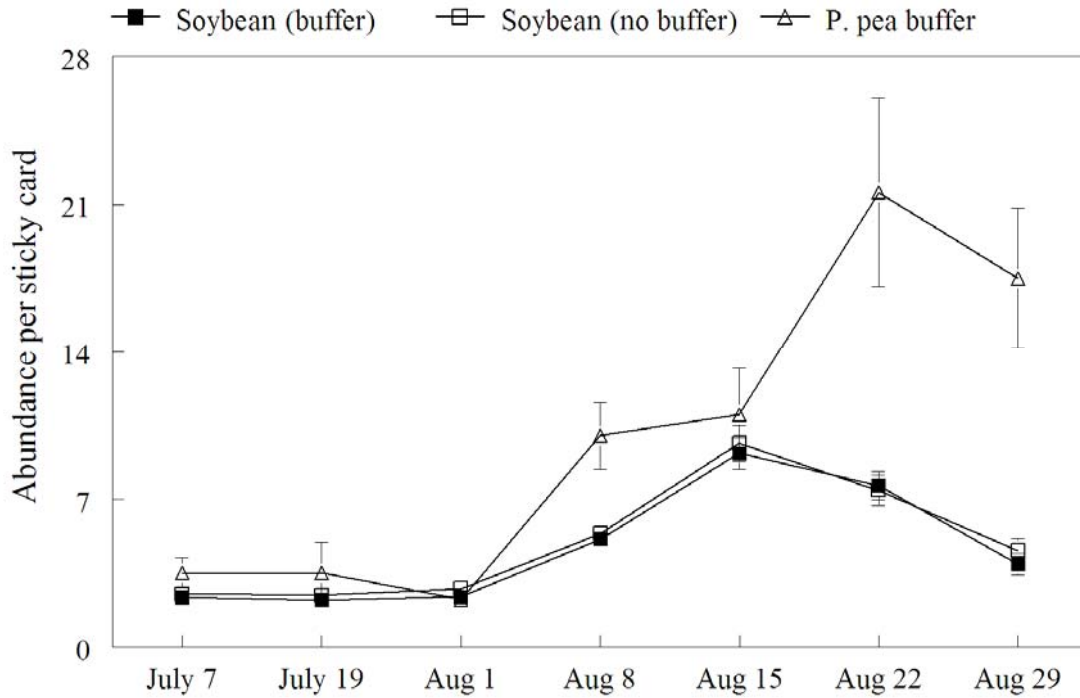
Figure 11. Mean number (±SEM) of mymarid wasps captured by sticky cards in opposite ends of soybean strips with and without an adjacent partridge pea buffer. Data are pooled over sampling sites at various distances from field edge. Abundance data collected at 3 m within partridge pea are also displayed for comparison. Based on an analysis of data from all 3 m sampling sites, partridge pea harbored significantly more mymarids than did the soybean strips at both ends ($F_{(2,48.4)} = 6.17$, $p = 0.004$); however, the buffer had no significant impact on mymarid abundance in soybean. 2006.
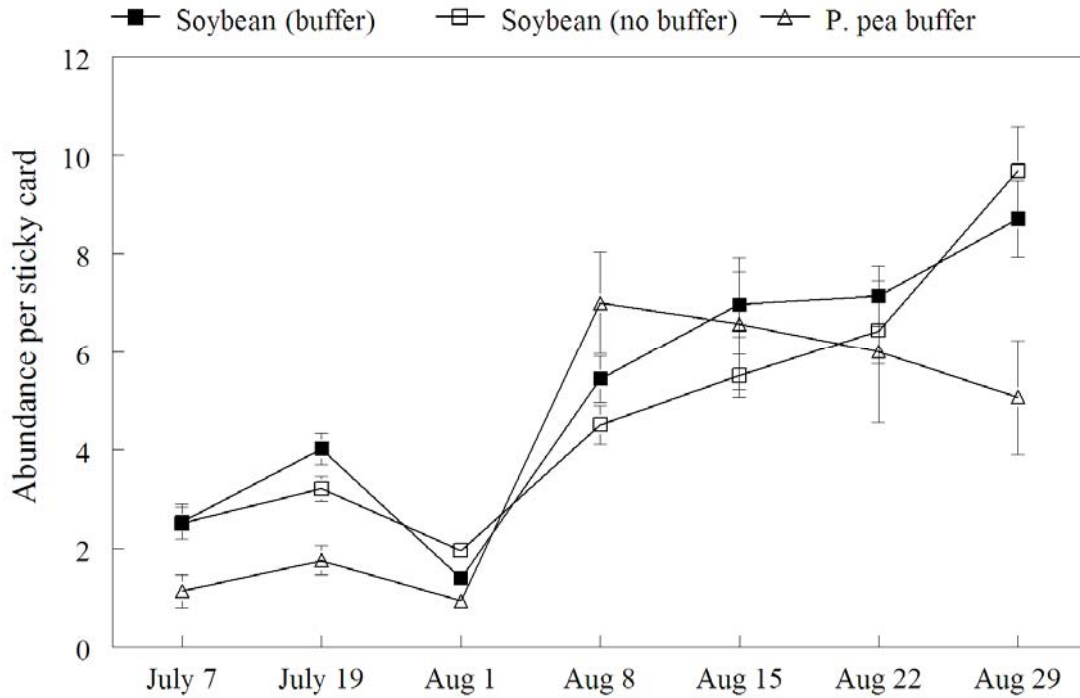
Figure 12. Mean number (±SEM) of trichogrammatid wasps captured by sticky cards in opposite ends of soybean strips with and without an adjacent partridge pea buffer. Data are pooled over sampling sites at various distances from field edge. Abundance data collected at 3 m within partridge pea are also displayed for comparison. Abundance of wasps in opposite soybean ends significantly changed with sampling date ($F_{(6,581)} = 2.52$, $p = 0.021$) but were not affected by the buffer. 2006.
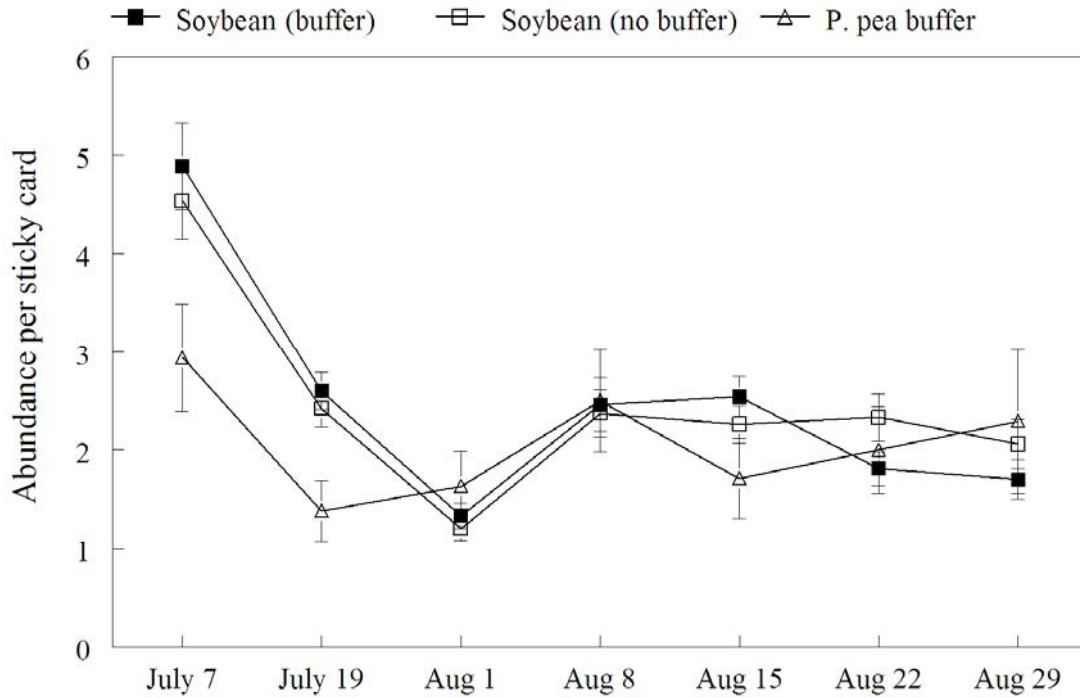
Figure 13. Mean number (±SEM) of scelionid wasps captured by sticky cards in opposite ends of soybean strips with and without an adjacent partridge pea buffer. Data are pooled over sampling sites at various distances from field edge. Abundance data collected at 3 m within partridge pea are also displayed for comparison. Sampling date was significant ($F_{(6,548)} = 33.51$, $p < 0.0001$), but main and interaction effects of buffer and distance from the field edge were not significant. 2006.
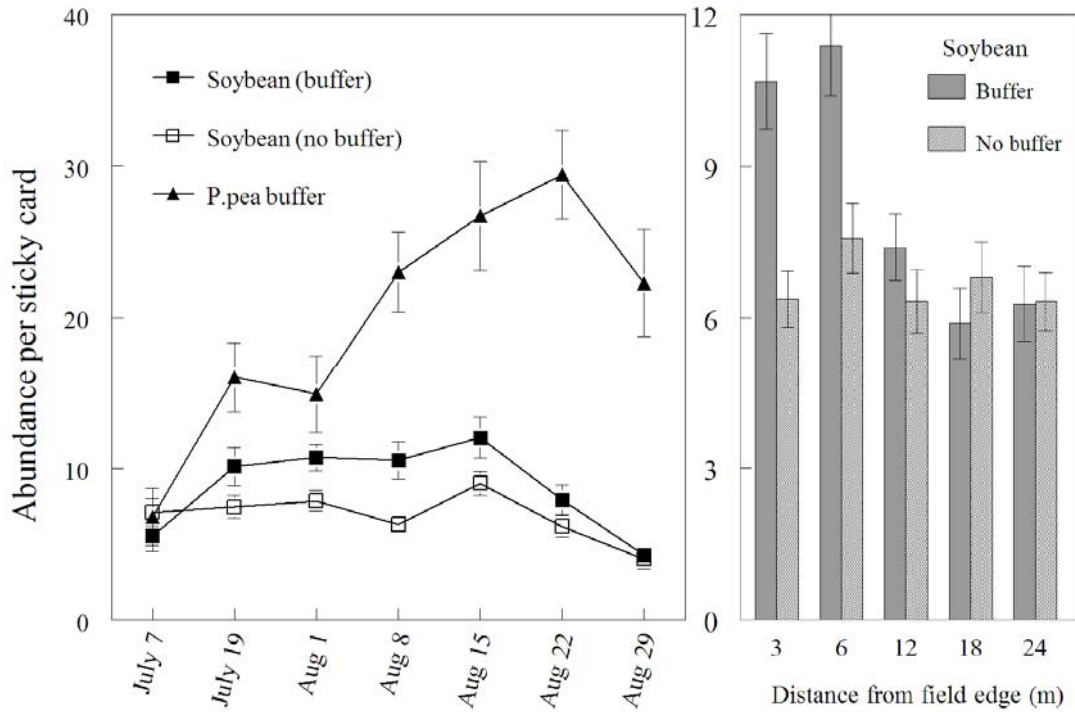
Figure 14. Mean number (±SEM) of sarcophagid/tachinid flies captured by sticky cards in opposite ends of soybean strips with and without an adjacent partridge pea buffer (line graph). Data are pooled over sampling sites at various distances from field edge. Abundance data collected at 3 m within partridge pea are also displayed for comparison. Flies were more abundant at soybean sites next to the buffer but differences varied with sampling date ($F_{(6,605)} = 2.76$, $p = 0.012$). Mean number of sarcophagid/tachinid flies (±SEM) was significantly higher at sampling sites near the soybean crop-buffer interface ($F_{(4,225)} = 4.53$, $p = 0.002$) (bar chart). 2006.
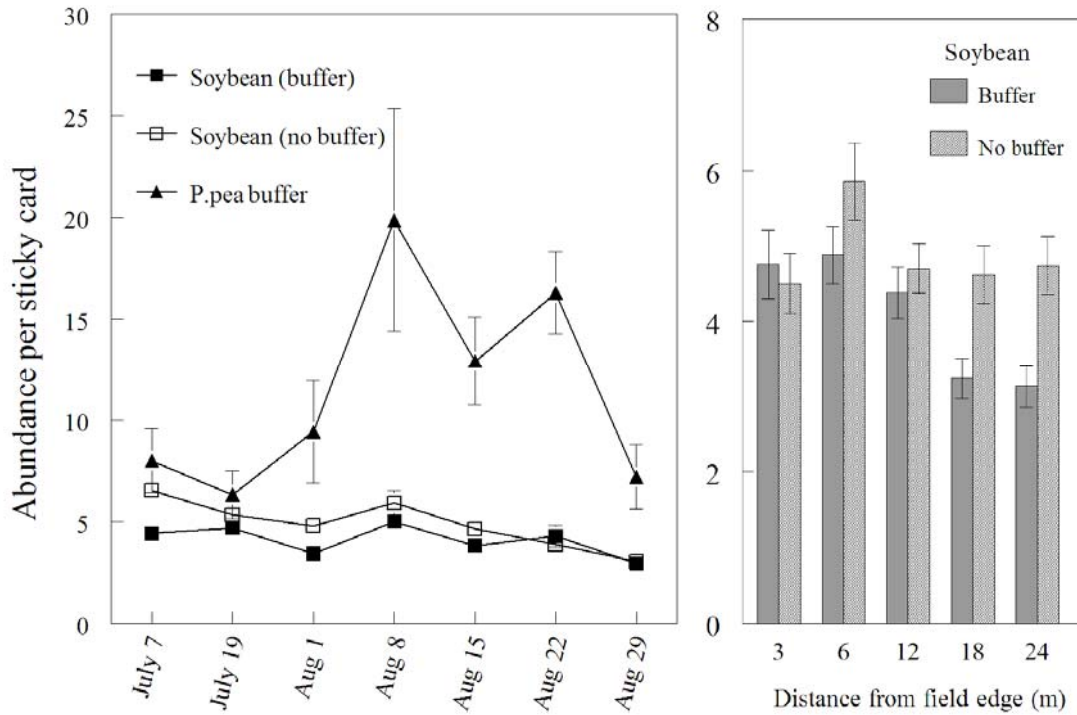
Figure 15. Mean number (±SEM) of arthropod predators captured by sticky cards in opposite ends of soybean strips with and without an adjacent partridge pea buffer (line graph). Data are pooled over sampling sites at various distances from field edge. Abundance data collected at 3 m within partridge pea are also displayed for comparison. Predator abundance was higher at the end of soybean strips without buffers ($F_{(1,231)} = 7.44$, $p = 0.007$). Mean number (±SEM) of predators varied across the transect of sampling sites at opposite ends of the soybean strips due to buffer and sampling date effects ($F_{(24,602)} = 1.83$, $p = 0.01$) (bar graph). 2006.

Figure 16. Mean number (±SEM) of arthropod herbivores captured by sticky cards in opposite ends of soybean strips with and without an adjacent partridge pea buffer. Data are pooled over sampling sites at various distances from field edge. Abundance data collected at 3 m within partridge pea are also displayed for comparison. The only significant effect was sampling time ($F_{(6,627)} = 57.57$, $p < 0.001$). 2006.
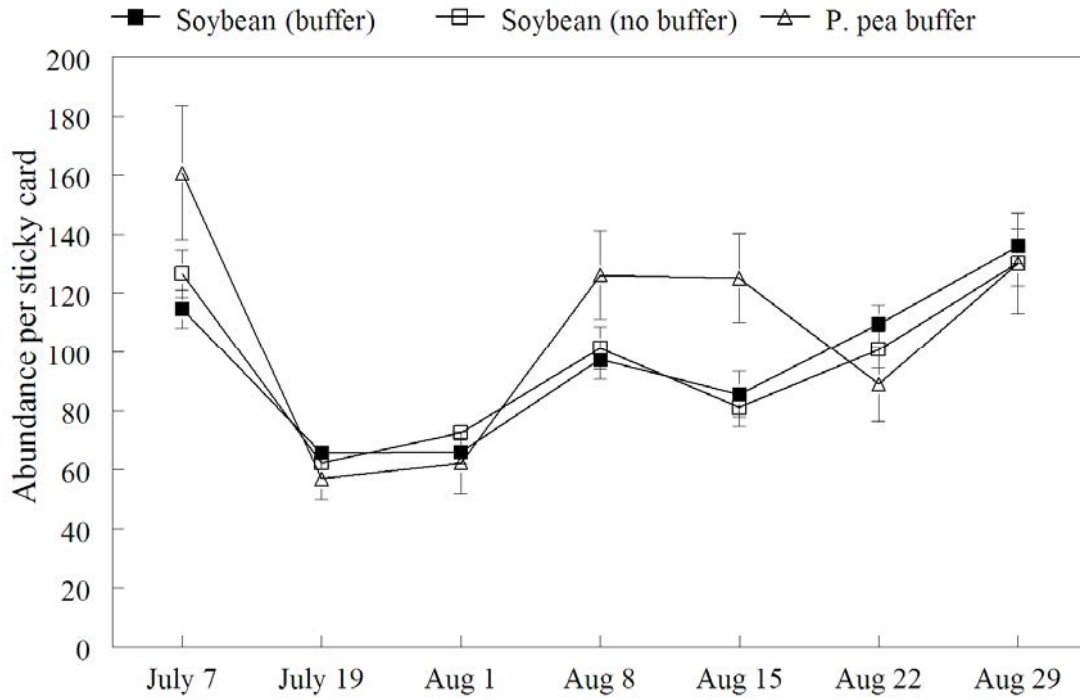
Figure 17. Mean number (±SEM) of arthropod saprovores captured by sticky cards in opposite ends of soybean strips with and without an adjacent partridge pea buffer (line graph). Data are pooled over sampling sites at various distances from field edge. Abundance data collected at 3 m within partridge pea are also displayed for comparison. Saprovores were more abundant at soybean sites next to the buffer but differences varied with sampling date ($F_{(6,653)}$ = 3.55, p = .0018). Mean numbers (±SEM) were significantly higher at sampling sites near the soybean crop-buffer interface ($F_{(4,212)}$ = 3.92, p = .0043). 2006.

Figure 18. Mean number (±SEM) of arthropod predators captured by pitfall trap in opposite ends of soybean strips with and without an adjacent partridge pea buffer. Data are pooled over sampling sites at various distances from field edge. Abundance data collected at 3 m within partridge pea are also displayed for comparison. The only significant effect was sampling time ($F_{(5,514)}$ = 10.99, p < 0.001). 2006.
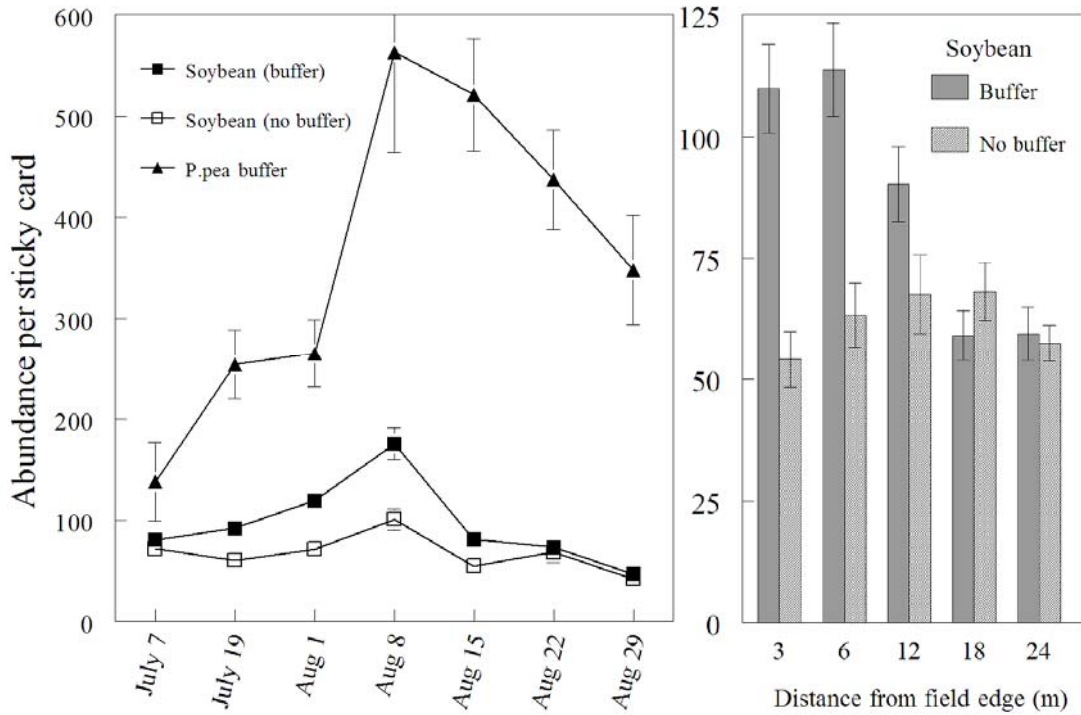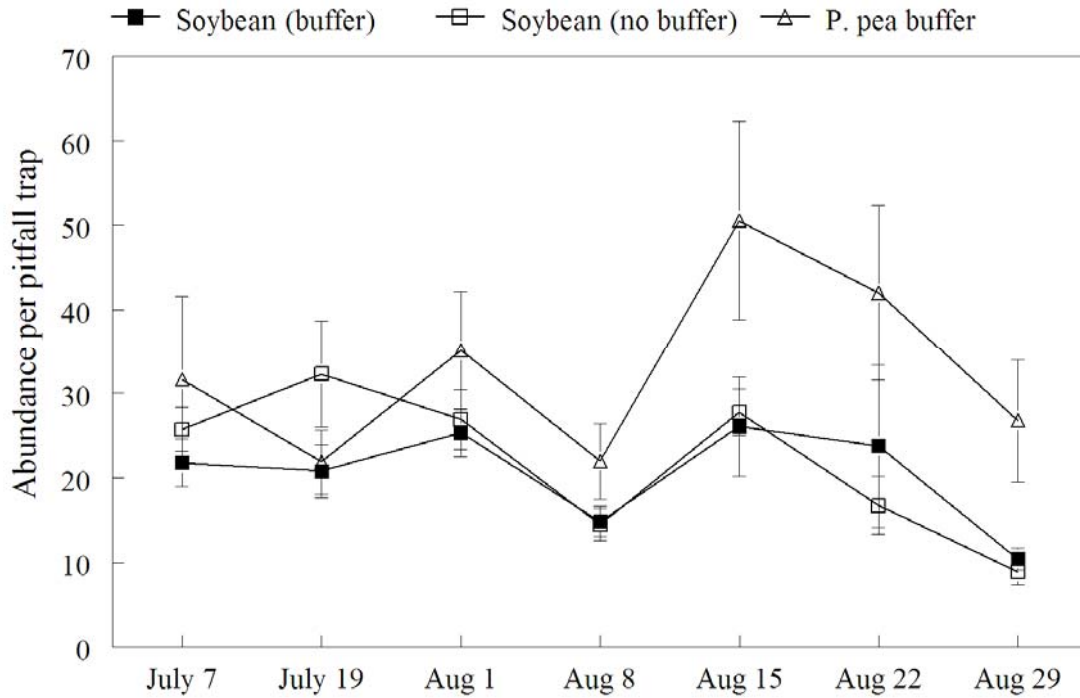
Literature Cited

Allaby M. (1999). "Scelionidae." <u>A Dictionary of Zoology</u>. 1999. Retrieved December 30, 2009 from Encyclopedia.com: http://www.encyclopedia.com/doc/1O8-Scelionidae.html.

Altieri MA, Letourneau DK. 1982. Vegetation management and biological control on agroecosystems. Crop Protection 1: 405-430.

Baggen LR, Gurr GM. 1998. The influence of food on *Copidosoma koehleri* (Hymenoptera: Encyrtidae), and the use of flowering plants as a habitat management tool to enhance biological control of potato moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae). Biological Control 11: 9-17.

Baggen LR, Gurr GM, Meats A. 1999. Flowers in tri-trophic systems: mechanisms allowing selective exploitation by insect natural enemies for conservation biological control. Entomologia Experimentalis et Applicata 91: 155-161.

Bell VA, Brightwell RJ, Lester PJ. 2006. Increasing vineyard floral resources may not enhance localised biological control of the leafroller *Epiphyas postvittana* (Lepidoptera: Tortricidae) by *Dolichogenidea* spp. (Hymenoptera: Braconidae) parasitoids. Biocontrol Science and Technology, 16(10): 1031-1042.

Berndt LA, Wratten SD, Hassan PG. 2002. Effects of buckwheat flowers on leafroller (Lepidoptera: Trotricidae) parasitoids in a New Zealand vineyard. Agricultural and Forest Entomology 4: 39-45.

Berndt LA, Wratten SD, Scarratt SL. 2006. The influence of floral resource subsidies on parasitism rates of leafrollers (Lepidoptera: Tortricidae) in New Zealand vineyards. Biological Control 37: 50-55.

Bianchi FJJA, Booij CJH, Tscharntke T. 2006. Sustainable Pest Regulation in Agricultural Landscapes: A Review on Landscape Composition, Biodiversity, and Natural Pest Control. Proceedings of the Royal Society B Biological Sciences 273:1715–1727.

Bianchi FJJA, Wäckers FL. 2008. Effects of flower attractiveness and nectar availability in field margins on biological control by parasitoids. Biological Control 46 (3), 400–408.

Blank, Peter. 2010. Personal communication. August 4, 2010.

Bone NJ, Thomson LJ, Ridland PM, Cole P, Hoffmann AA. 2009. Cover crops in Victorian apple orchards: effects on production, natural enemies and pests across a season. Crop Protection 28: 675-683.

Bugg RL, Dutcher JD. 1989. Warm-season cover crops for pecan orchards: horticultural and entomological implications. Biological Agriculture and Horticulture 6: 123-148.

Chaney WE. 1998. Biological control of aphids in lettuce using in-field insectaries, pp. 73-83 in CH Pickett and RL Bugg [eds.], Enhancing Biological Control – Habitat Management to promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley CA.

Danyk T, Johnson DL, Mackauer M. 2000. Parasitism of the grasshopper *Melanoplus sanguinipes* by a sarcophagid fly *Blaesoxipha atlanis*: influence of solitary and gregarious development on host and parasitoid. *Entomologia Experimentalis et Applicata* 94: 259–268.

Ellis JA, Walter AD, Tooker JF, Ginzel MD, Reagel PF, Lacey ES, Bennett AB, Grossman EM, Hanks LM. 2005. Conservation biological control in urban landscapes: Manipulating parasitoids of bagworm (Lepidoptera: Psychidae) with flowering forbs. Biological Control 34(1): 99-107.

English-Loeb G, Rhainds M, Martinson T, Ugine T. 2003. Influence of flowering cover crops on *Anagrus* parasitoids (Hymenoptera: Mymaridae) and *Erythroneura* leafhoppers (Homoptera: Cicadellidae) in New York vineyards. Agricultural and Forest Entomology 5: 173 – 181.

Foote LE, Jackobs JA. 1966. Soil factors and the occurrence of partridge pea (*Cassia fasciculata* Michx.) in Illinois. Ecology 47: 968-975.

Gibson GAP. 1993. Superfamilies Mymarommatoidea and Chalcidoidea. In: Hymenoptera of the word: An Identification guide to families. Goulet, H. and Huber, J.T. (eds). pp. 570-655. Centre for Land and Biological Resources Research. Ottawa, Canada.

Grenier S. 1988. Applied biological control with tachinid flies (Diptera: Tachinidae): a review. Anzeiger für Schädlingskunde, Pflanzenschutz, Umweltschutz, 61, 49–56.

Gourdine JS, Simmons AM, Mccutcheon GS, Leibee GL. 2005. Floral Nectars and Honey Enhance Survival of *Diadegma Insulare* (Hymenoptera: Ichneumonidae), a Parasitoid of the Diamondback Moth (Lepidoptera: Plutellidae). Journal of Entomological Science. 40:96-99.

Gurr GM, Wratten SD, Tylianakis J, Kean J, Keller M. 2005. Providing plant foods for insect natural enemies in farming systems: balancing practicalities and theory. In: Wackers FL, van Rijn PCJ, Bruin J (Eds.), Plant-provided Food for Carnivorous Insects: A Protective Mutualism and its Applications. Cambridge University Press, Cambridge.

Harvey JA, Wagenaar R. 2006. Development of the herbivore *Pieris rapae* and its endoparasitoid *Cotesia rubecula* on crucifers of field edges. Journal of Applied Entomology. 130(9-10), 465–470.

Heimpel GE, Jervis MA. 2005. Does floral nectar improve biological control by parasitoids? In: Wäckers, F.L., van Rijn, P.C.V., Bruin, J. (Eds.), Plant-provided food for carnivorous insects: a protective mutualism and its applications. Cambridge University Press, Cambridge.

Herrick CA. 1921. A Sarcophagid Parasite of the Common Field Cricket. Transactions of the American Microscopical Society 40: 115-116.

Hickman J, Wratten SD. 1996. Use of *Phacelia tanacetifolia* strips to enhance biological control of aphids by hoverfly larvae in cereal fields. J. Econ. Entomol. 89: 832-840.

Hobson M. 1972. *Cassia fasciculata*. In I.W. Hardin, C. Doersken, M Hobson, D Herndon, and F Thomas, editors. Pollination ecology and floral biology of four weedy genera in southern Oklahoma. Southwestern Naturalist 16:403-412.

Irvin NA, Wratten SD, Frampton CM. 2000. Understory management for the enhancement of the leafroller parasitoid *Dolichogenidea tasmanica* (Cameron) in orchards at Canterbury, New Zealand, pp. 396-403. *In* Austin, A. D. and M. Dowton (eds). Hymenoptera: Evolution, Biodiversity and Biological Control. CSIRO Publishing, Collingwood, Victoria, Australia.

Jervis MA, Kidd NAC. 1986. Host-feeding strategies in hymenopteran parasitoids. Biological Reviews of the Cambridge Philosophical Society 61: 395-434.

Jervis MA, Kidd NAC, Fitton MG, Huddleson T, Dawah HA. 1993. Flower-visiting by hymenopteran parasitoids. Journal of Natural History 27: 67-105.

Kelly CA. 1986. Extrafloral Nectaries: Ants, Herbivores, and Fecundity in *Cassia fasciculata*. Oecologia 69: 600-605.

Kelly KOG. 1914. A New Sarcophagid Parasite of Grasshoppers. Agr. Research, 2:435-446.

Landis DA, Wratten SD, Guff GM. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology 42:175-210.

Landis DA, Menalled FD. 1998. Ecological considerations in the conservation of effective parasitoid communities in agriculture systems. Pages 101–121 in P. Barbosa, ed. Conservation Biological Control. San Diego: Academic.

Landis DA, Menalled FD, Costamagna AC, Wilkinson TK. 2005. Manipulating Plant Resources to Enhance Beneficial Arthropods in Agricultural Landscapes. Weed Science 53: 902-908.

Lavandero B, Wratten SD, Shishehbor P, Worner S. 2005. Enhancing the effectiveness of the parasitoid *Diadegma semiclausum* (Helen): Movement after use of nectar in the field. Biological Control 34: 152–158.

Lavandero B, Wratten SD, Didham RK, Gurr G. 2006. Increasing floral diversity for selective enhancement of biological control agents: a double-edged sword? Basic Appl. Ecol. 7, 236–243.

Lee TD, Bazzaz FA. 1982. Regulation of Fruit and Seed Production in an Annual Legume, *Cassia fasciculata*. Ecology 63: 1363-1373.

Lee JC, Heimpel GE. 2005. Impact of flowering buckwheat on Lepidopteran cabbage pests and their parasitoids at two spatial scales. Biological Control 34 (3), 290–301.

Lee JC, Heimpel GE, 2008. Floral resources impact longevity and oviposition rate of parasitoid in the field. Journal of Animal Ecology 77, 565–572.

Lee JC, Andow DA, Heimpel GE. 2006. Influence of floral resources on sugar feeding and nutrient dynamics of a parasitoid in the field. Ecological Entomology 31, 470–480.

Long RF, Corbett A, Lamb C, Reberg-Horton C, Chandler J, Stimmann M. 1998. Beneficial insects move from flowering plants to nearby crops. California Agriculture 53 (5), 23–26.

Loomans AJM. 2003. Parasitoids as Biological Control Agents of Thrips Pests. PhD Thesis, Wageningen Univ., Wageningen. 200pp.

Maier CT. 1981 Parasitoids emerging from puparia of *Rhagoletis pomonella* (Diptera: Tephritidae) infesting hawthorn and apple in Connecticut USA. Can. Entomol. 113: 867-870.

Masetti A, Lanzoni A, Burgio G. 2010. Effects of flowering plants on parasitism of lettuce leafminers (Diptera: Agromyzidae). Biological Control 54: 263–269.

Masner L. 1983. A revision of *Gryon* Haliday in North America (Hymenoptera: Proctotrupoidea: Scelionidae). The Canadian Entomologist 115: 123-174.

Masner L. 1993a. Superfamily Platygastroidea. In: Hymenoptera of the word: An Identification guide to families. Goulet, H. and Huber, J.T. (eds). pp. 558-565. Centre for Land and Biological Resources Research. Ottawa, Canada.

Masner L. 1993b. Superfamily Ceraphronoidea. In: Hymenoptera of the word: An Identification guide to families. Goulet, H. and Huber, J.T. (eds). pp. 566-569. Centre for Land and Biological Resources Research. Ottawa, Canada.

Morris MC, Li FY. 2000. Coriander (Coriandrum sativum) "companion plants" can attract hoverflies and may reduce pest infestation in cabbages. New Zealand Journal of Crop and Horticultural Science 28: 213-217.

Olson DM, Wäckers FL. 2007. Management of field margins to maximize multiple ecological services. Journal of Applied Ecology 44: 13–21.

Patt JM, Hamilton GC, Lashomb JH. 1997. Foraging success of parasitoid wasps on flowers: interplay of insect morphology, floral architecture and searching behavior. Entomologia Experimentalis et Applicata 83: 21-30.

Pilkington LJ, Irvin NA, Boyd EA, Hoddle MS, Triapitsyn, SV, Carey BG, Jones WA, Morgan JW. 2005. Introduced parasitic wasps could control glassy-winged sharpshooter. Calif. Agric. 59 (4), 223–228.

Platt JO, Caldwell JS, Kok LT. 1999. Effect of buckwheat as a flowering border on populations of cucumber beetles and their natural enemies in cucumber and squash. Crop Protection 18: 305-313.

Rebek EJ, Sadof CS, Hanks LM. 2006. Influence of floral resource plants on control of an armored scale pest by the parasitoid *Encarsia citrina* (Craw.) (Hymenoptera: Aphelinidae). Biological Control 37: 320–328.

Robinson KA. 2009. Use of floral resources by the lacewing *Micromus tasmaniae* and its parasitoid *Anacharis zealandica*, and the consequences for biological control by *M. tasmaniae*. Oecologia 96:439–449.

Scarratt SL Wratten SD, Shishehbor P. 2008. Measuring parasitoid movement from floral resources in a vineyard. Biological Control 46 (2), 107–113.

Sengonca M, Frings B. 1988. Einfluss von *Phacelia tanacetifolia* auf Schaedlings- un Nuetzlingspopulationen in Zuckerrubenfeldern. (Influence of *Phacelia tanacetifolia* on pests and beneficial insects in sugarbeet plots). Pedobiologia 32: 311-316.

Settle WH, Ariawan H, Astuti ET, Cahyana W, Hakim AL, Hindayana D, Lestari AS, Sartanto P. 1996. Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. Ecology 77:1975-1988.

Stephens MJ, France CM, Wratten SD, Frampton C. 1998. Enhancing biological control of leafrollers (Lepidoptera: Tortricidae) by sowing buckwheat (*Fagopyrum esculentum*) in an orchard. Biocontrol Science and Technology 8: 547-558.

Sustainable Agriculture Research and Education. 2008. Optimizing Environmental Benefits From Riparian Buffers in Maryland.

<http://www.sare.org/MySare/ProjectReport.aspx?do=viewRept&pn=LNE04-201&y=2008&t=1> Accessed July 22, 2010.

Tylianakis JM, Didham RK, Wratten SD. 2004. Improved fitness of aphid parasitoids receiving resource subsidies. Ecology 85 (3), 658–666.

Ulrich H. 2005. Predation by adult Dolichopodidae (Diptera): a review of literature with an annotated prey-predator list. *Studia dipterologica* 11**:** 369-403.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2006. Plant Guide: Partridge Pea. <http://plants.usda.gov/plantguide/doc/pg_chfa2.doc> Accessed May 2, 2010.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2009a. Maryland CREP Technical Handbook. <ftp://ftp-fc.sc.egov.usda.gov/MD/web_documents/programs/crep/NRCS_CREP_Tech_Handbook_102309.pdf> Accessed May 2, 2010.

U.S. Department of Agriculture, Natural Resources Conservation Service Maryland. 2009b. Maryland Conservation Practice Standard: Filter Strip, January 2009. <http://efotg.nrcs.usda.gov/references/public/MW/MD393_final_1_09.pdf> Accessed May 2, 2010.

U.S. Department of Agriculture, Natural Resources Conservation Service Maryland. 2009c. Maryland Native Wildflower Mixes, Approved Custom Grass-Wildflower Mixes for Conservation Cover (327), March 2009. < http://efotg.sc.egov.usda.gov/references/public/MW/MD327_09_wildflowermixes.pdf > Accessed August 5, 2010.

Vollhardt IMG, Bianchi FJJA, Wäckers FL, Thies C, Tscharntke T. 2010. Spatial distribution of flower vs. honeydew resources in cereal fields may affect aphid parasitism. Biological Control 53: 204-213.

Wäckers FL. 2004. Assessing the suitability of flowering herbs as parasitoid food sources: flower attractiveness and nectar accessibility. Biological Control 29: 307–314.

Wanner H, Gu H, Gunther D, Hein S, Dorn S. 2006a. Tracing spatial distribution of parasitism in fields with flowering plant strips using stable isotope marking. Biological Control 39 (2), 240–247.

Wanner H, Gainan G, and Dorn S. 2006b. Nutritional value of floral nectar sources for flight in the parasitoid wasp, *Cotesia glomerata*. Physiological Entomology 31: 127-133.

Williams IH, Christian DG. 1991. Observations on *Phacelia tanacetifolia* Bentham (Hydrophyllaceae) as a food plant for honey bees and bumble bees. J. Apicult. Res. 30: 3–12.

Winkler K, Wäckers FL, Bukovinszkine-Kiss G, van Lenteren, JC. 2006. Sugar resources are vital for *Diadegma semiclausum* fecundity under field conditions. Basic and Applied Ecology 7, 133–140.

Wratten SD, van Emden, HF. 1995. Habitat manipulation for enhanced activity of natural enemies of insect pests. In: Glen DM, Greaves MP, Anderson HM. (Eds.), Ecology and Integrated Farming Systems. Wiley, Chichester, UK, pp. 117-145.

Yang P, Foote D, Alyokhin AV, Lenz L, Messing RH. 2002. Distribution and Abundance of Mymarid Parasitoids (Hymenoptera: Mymaridae) of *Sophonia*

rufofascia Kuoh and Kuoh (Homoptera: Cicadellidae) in Hawaii. Biological Control 23: 237–244.

Zhao JZ, Ayers GS, Grafius EJ, Stehr FW. 1992. Effects of neighboring nectar producing plants on populations of pest Lepidoptera and their parasitoids in broccoli plantings. Great Lakes Entomologist 25 (4), 253–258.

Zimmer M, Diestelhorst O, Lunau K. 2003. Courtship in long-legged flies (Diptera: Dolichopodidae): function and evolution of signal. Behavioral Ecology 14(4): 526-530.