Extrafloral Nectar in an Apple Ecosystem to Enhance Biological Control

M. W. BROWN, CLARISSA R. MATHEWS, AND GREG KRAWCZYK

ABSTRACT A common goal of conservation biological control is to enhance biodiversity and increase abundance and effectiveness of predators and parasitoids. Although many studies report an increase in abundance of natural enemies, it has been difficult to document increases in rates of biological control. To enhance parasitism of the tufted apple bud moth, Platynota idaeusalis (Walker) (Lepidoptera: Tortricidae), alternate food was provided by interplanting peaches bearing extrafloral nectaries into apple (Malus spp.) orchards. Laboratory studies showed that the presence of nectar increased longevity and parasitism rates by Goniozus floridanus (Bethylidae), the dominant parasitoid of tufted apple bud moth in West Virginia. In orchard studies, we found the total number of hymenopteran parasitoids was higher on peach (Prunus spp.) trees than on adjacent apple trees. Abundance of parasitic Hymenoptera was also significantly higher on the side of traps facing away from rather than toward peach trees, indicating attraction to peach trees. However, total parasitism rates of tufted apple bud moth were not affected by the presence of peach extrafloral nectar in any field studies. Insect injury to fruit at harvest showed that fruit from orchards with interplanted peach trees had less injury from San Jose scale, Quadraspidiotus perniciosus (Comstock) and stink bugs (Pentatomidae) than fruit from an apple monoculture. Although interplanting with peach trees did not produce the hypothesized result of increased biological control, the experiment did have beneficial results for pest management. These results demonstrate the importance of collecting data on variables beyond the targeted species when evaluating habitat manipulation experiments to fully assess the impact on the ecosystem.

KEY WORDS apple, conservation biological control, Goniozus floridanus, Platynota idaeusalis, extrafloral nectar

Modifying agroecosystems to provide habitat for natural enemies of arthropod pests, called conservation biological control, is a growing area of research (Barbosa 1998, Landis et al. 2000, Straub et al. 2008). Fruit orchard systems are relatively stable temporally and spatially thus making them suitable for habitat manipulation to enhance pest management (Brown 1999). Apple production in the eastern United States is complicated by a large number of potential pests (Slingerland and Crosby 1914, Aghello et al. 2006) but also benefits from a very diverse community of predators and parasitoids that feed on these herbivores (Brown and Schmitt 2001). It has been shown that adding flowering companion plants to the apple ecosystem in eastern North America can significantly reduce the need for insecticide applications without increasing insect damage to fruit (Brown and Glenn 1999, Bostanian et al. 2004). However, adding companion plants to orchards was not found to be economically sustainable due to reduced yield (Brown and Glenn 1999). Numerous other attempts at conservation biological control have shown promise but have not yet been found to be generally acceptable due to operational difficulties leading to a lack of economical incentive for implementation (Brown 2008).

The use of plant-provided foods such as nectar and pollen (Wacker et al. 2005) has been especially attractive for conservation biological control studies because the food resources are presented in a natural manner with little or no additional operational interventions. Many parasitoids require honeydew or floral or extrafloral nectar as an energy source (Wacker 1999). Even synovigenic species (those that produce ova throughout their adult life) that feed on hosts often require plant-provided saccharides for energy (Heimpel et al. 1997). Laboratory studies have shown that nectar can increase the flight activity, longevity, and fecundity of parasitoids (Shearer and Atanasov 2004, Berndt and Watten 2005; Wanner et al. 2006, Lee and Heimpel 2008) and predators (Limburg and Rosenheim 2001, Taylor and Pfannenstiel 2008).
There have been some successes increasing biological control in the field by planting nectar-producing plants (Lee and Heimpel 2005; Mathews et al. 2007), but the majority of field studies have not documented increased biological control (Andow 1991, Elder 1998, Jonsson et al. 2008). Agroecosystems are complex with hosts and other required resources often located in different habitats, forcing parasitoids to expend energy in flight between these two resources (Lewis et al. 1998). Therefore, more effective biological control may be attainable by creating ecosystems where food and hosts are co-mingled in the same habitat.

There are many parasitoids of the tufted apple bud moth, Platynota iaeudaalis (Walker) (Lepidoptera: Tortricidae), in North America (Biddinger et al. 1994). We selected Coniopteryx floridana (Ashmead) (Hymenoptera: Bethylidae) as a model to further examine the interaction between parasitoid-host-extraloral nectar in the lab because it was the most abundant parasitoid in our orchards (M.W.B., unpublished data). \textit{G. floridana} is a gregarious, ectoparasitoid of tortricid larvae and is synovigenic (Evans 1964). It feeds on both hosts and nectar in the laboratory (C.R.M., unpublished data). Although it is abundant in our research orchards it was not found during 4 yr of sampling in Pennsylvania orchards (Biddinger et al. 1994). A congeneric species, Coniopteryx platynota Ashmead, was found to be the most abundant species in 1952 in Missouri, on Argyrotaenia veletina (Walker) (Oatman and Jenkins 1962) and Coniopteryx jactana Ferrogia is a parasitoid on the light brown apple moth, Epiphyas postvittana (Walker), in Australia (Danhanumrayana 1980).

In this study, we attempted to increase parasitism of tufted apple bud moth by interplanting extraloral nectar-producing peach trees into apple orchards. Data were gathered on several response variables in the apple ecosystem to fully evaluate the effect of habitat manipulation. We measured the effect of extraloral nectar on longevity and parasitism rate of \textit{G. floridana} in the lab, total parasitism rates of tufted apple bud moth in the field, total parasitoid abundance in the field, and total insect damage to fruit at harvest.

**Materials and Methods**

**Laboratory Studies.** Laboratory experiments were done to test the hypothesis that peach extraloral nectar increases the longevity of \textit{G. floridana} and its parasitism of tufted apple bud moth. First-instar tufted apple bud moth larva were obtained from The Pennsylvania State University, Fruit Research and Extension Center, Biglerville, PA. The colony has been in continuous rearing for several years in the laboratory, being supplemented with fresh, field-collected larvae each season. Larvae were transported to Shepherd University, Shepherdstown, WV, where they were kept on a lima bean diet (Shorey and Hale 1965) at $23 \pm 1^\circ C$ and a photoperiod of 14:10 (L:D) h until the third to fourth instar, when they were susceptible to parasitism by \textit{G. floridana}. Larvae were then transferred to 8.5-cm-diameter by 2-cm-deep petri dishes containing two clean apple leaves with the petiole inserted into moist plant growing medium. The apple leaves were from greenhouse or orchard trees that had not been treated with insecticides. Three larvae were placed on the apple leaves and left to acclimate for 24–48 h. Each dish also contained a moist 1.5- by 0.5-cm cotton wick to provide moisture.

To study longevity of adult \textit{G. floridana}, newly emerged adult females reared from field collected tufted apple bud moth larvae were held with male parasitoids and water but were not provided food. After 24-h starvation, one female parasitoid was placed in a petri dish with three tufted apple bud moth larvae and apple leaves; this is termed the first provision hereafter. After 48 h, the wasp was removed and provided with a second dish with three new host larvae on two fresh leaves; termed the second provision hereafter. After another 48 h, the wasp was removed again and provided with only the moist wick and monitored until death. Twenty-one female \textit{G. floridana} were handled in this way as a control; another 21 were handled the same way except for also being provided with 1 \textit{μL} of peach extraloral nectar throughout the study. The nectar was collected from greenhouse peach trees by placing a micropipette tube on a nectar gland at the base of a leaf blade and stored in a freezer until use. Water, and nectar in the treated replicates, were replaced every 48 h. Previous drops of nectar were removed before addition of another drop to prevent mold growth.

To study the effect of extraloral nectar on short-term parasitism rate, female \textit{G. floridana} of unknown age from a laboratory colony (23 ± 1°C and a photoperiod of 14:10 [L:D] h) were used. The colony had male and female parasitoids from field-collected, parasitized tufted apple bud moth larvae and were provided with honey and water but not host larvae. Twenty-two females were given two provisions of three tufted apple bud moth larvae for the control and the extraloral nectar treatment as described in the longevity study. Nectar and water were replaced, as appropriate to the treatment, with the addition of the second provision of host larvae. Tufted apple bud moth larvae that had been exposed to parasitoids were removed from the petri dish and provided with fresh leaves, water wick and reared, one larva per dish. The exposed larvae were monitored daily until parasitoids emerged or a host pupa formed. Water and fresh leaves were provided as needed. Specimens of \textit{G. floridana} reared from field-collected tufted apple bud moth larvae and from those used in laboratory experiments are deposited in the West Virginia University Entomology Museum, Morgantown WV.

Data for both the longevity and parasitism studies were analyzed with a \textit{t}-test to compare differences between control and extraloral nectar treatment. The parasitism data, pooled over both provisions, required \log(x + 1) transformation for statistical analysis; the longevity data did not need transformation.

**Field Plots.** All field studies were conducted in research orchards at the Appalachian Fruit Research Station, Kearneysville, WV, from 2004 to 2006. Insec-
ticicides were not used in any treatment or control orchard but all other standard horticultural management, including herbicide and fungicide applications were conducted as in standard orchard management for the region (Pennsylvania State University 2008). The first two experiments on point-source attraction and distance attraction to nectar source were done in a 0.5 ha apple block of ‘Gale Gala’ and ‘Sun Fuji’, half on M26 and half on EMLA7 roots, planted in December 2001. Tree rows were spaced at 4.9 m and trees within rows were spaced at 2.4 m for M26 and at 3.7 m for EMLA7.

The last two experiments on testing nectar concentration effects on parasitoids and harvest evaluations were conducted in three interplanted orchards, each matched with a control orchard. Two 0.5 ha orchards were interplanted with 50% apple (half 'Royal Empire' on M9/EMLA111 roots and half 'Granny Smith' on EMLA26 roots) and 50% peach ('Loring' on 'Lovell' roots) producing extrafloral nectar. Interplanting was done by alternating two apple trees with two peach trees within each row. Tree spacing was 3.7 by 4.9 m, and the orchards were planted in April 1997. Each of these two orchards was matched with a control orchard with 0.25 ha apple planted as a monoculture with both 'Royal Empire' and Granny Smith separated from the experimental orchard by 10 m. All other aspects of the orchard design were as described for the experimental orchards. The third orchard, 0.15 ha, was planted with 9% peach trees. 'Crimson Rocket' on Lovell roots. The apples in this orchard were 'Liberty' and 'Enterprise' on M9 roots. Individual peach trees were interplanted in a regular pattern throughout the orchard. The orchard was planted in April 2002 at a spacing of 3.7 by 4.9 m. This orchard was paired with a control orchard, 20 m from the experimental orchard, but with the same planting design, size and cultivars, except with no peach trees. No data were collected from any border row trees in any experimental or control orchard.

**Point Source Attraction.** This experiment was done to test the hypothesis that peach extrafloral nectar increases the abundance of parasitoids and parasitism rates of tufted apple bud moth on apple. Eight plots were established in the apple orchard and replicated four times during the summer of 2005 in a randomized block design. Each plot had three equally spaced subplots: one with a potted Gala apple tree, one with a potted peach tree with extrafloral nectar glands and one with a potted peach tree without extrafloral nectar glands. The peach trees used in this experiment were from open-pollinated Lovell that had segregated into phenotypes that had either extrafloral nectar glands or no such glands (Mathews et al. 2007). All potted trees were 2-3 yr old, 1.5-m-tall, 3-cm trunk diameter and had a 1-m-diameter canopy. Treatment subplots were randomized for each replicate. On each potted tree a clear plastic dish with a 13-cm-diameter area coated with Tack Trap (Tanglefoot Co., Grand Rapids, MI) on both sides was attached. Sticky traps also were attached to each of the four adjacent apple trees in the orchard. These trees were 2.7 m from the potted tree in the half of the orchard with M26 rootstock and 3.1 m in the EMLA7 half. Number of parasitoids was recorded on each trap, recording the number of parasitoids on each trap face (facing the potted tree and facing away from the potted tree) separately. Traps were left in the orchard for 1 wk, being placed in the orchard on 21 May, 17 June, 22 July, and 22 August. Numbers of parasitoids per trap face were analyzed by a t-test combining all replicates during the year for the potted tree and the adjacent apple trees separately. Comparisons of numbers of parasitoids among treatments were done with an analysis of variance (ANOVA) (SAS Institute 2001). These data fit the assumptions of the statistical tests without transformation.

To measure parasitism rate, individual second- to third-instar host larvae from the Penn State colony were placed in 8.5-cm-diameter by 2-cm-deep petri dishes with two clean apple leaves. The larvae were allowed to make their nests between the two leaves and feed for 2-3 d until they were third to fourth instar. The larvae and their nests were pinned onto orchard tree leaves, one per leaf, for exposure to parasitism. Two sentinel tufted apple bud moth larvae were placed on each of the adjacent four orchard trees at the same time sticky traps were in the orchard and recovered 5 d later. Larvae were returned to the laboratory and placed in a growth chamber (25 ± 1°C and a photoperiod of 16:8 (L:D) h) until either parasitized or an adult moth emerged. Percentage of parasitized larvae (combining all species of parasitoids), calculated using number of parasitized larvae divided by the number parasitized plus adult moths, was determined for each subplot. Due to an inability to normalize the data, differences in percent parasitism were analyzed with a chi-square test (SAS Institute 2001) for treatment effect.

**Distance Attraction.** This experiment was done to test the hypothesis that abundance of parasitoids and tufted apple bud moth parasitism are dependent upon the distance from the nectar source. Point sources of extrafloral nectar were placed in the apple orchard in the form of a cluster of three potted peach trees in 2006. Three potted peach trees, all producing extrafloral nectar and the same size and age as in the previous study, were used to simulate the same amount of foliage as in one of the orchard apple trees. Sample apple trees were selected in four perpendicular transects extending diagonally across tree rows with three apple trees per transect. Because of the differences in tree spacing, distances between sample trees were 2.7 or 3.1, 8.2 or 9.2, and 13.6 or 15.4 m. Five plots, three at the smaller and two at the larger spacing, were established during each of four replicates with experiments beginning 19 May, 22 June, 25 July, and 6 September.

One clear plastic sticky trap, as described in the point source attraction study, was placed on each sample tree and on the potted peach trees. After one week, traps were collected to count the number of parasitic Hymenoptera on each face of the trap. Two sentinel third- to fourth-instar tufted apple bud moth
larvae were placed on each sample tree as described previously. They were left in the orchard exposed to parasitoids for 5 d, removed to the laboratory, and held in a growth chamber (25 ± 1°C and a photoperiod of 16:8 [LD] h) until parasitized or a moth emerged. Percentage of parasitized larvae (combining all species of parasitoids), calculated using number of parasitized larvae divided by the number parasitized plus adult moths, was determined for each subplot. Number of parasitoids between trap faces, was analyzed by a t-test combining all replicates during the year for the potted tree and the adjacent apple trees separately. Comparisons among distances from the potted trees were done with an ANOVA (SAS Institute 2001) for both number of parasitoids and percent parasitism. Data fit the assumptions of statistical tests without transformation.

Nectar Concentration. This experiment tested the hypothesis that parasitism of tufted apple bud moth is enhanced by increasing the concentration of nectar sources in the orchard. Parasitism was compared between the interplanted orchards and their matched control apple orchards with two replicates in 2004 and four in years 2005 and 2006. For each replicate, 100 sentinel tufted apple bud moth larvae, as stated previously, were pinned onto apple leaves on orchard trees in the 50% interplanted orchard; 50 larvae were placed in the 9% interplanted orchard because of its smaller size. Equal numbers of larvae were placed in the matching control orchards. Sentinel larvae were not placed in border rows of the orchard to increase the effective size of the buffer between treatments. Larvae were put into the field on 25 June and 4 August in 2004; 23 May, 22 June, 27 July, and 25 August in 2005; and 19 May, 22 June, 25 July, and 8 September in 2006. There was an additional replicate in the 9% interplanted orchard and its control on 9 July 2004. Larvae were collected after 5 d in the orchard and taken to the laboratory for rearing in a growth chamber (25 ± 1°C and a photoperiod of 16:8 [LD] h) until parasitized or a moth emerged. Percentage of parasitized larvae (combing all species of parasitoids), calculated using number of parasitized larvae divided by the number parasitized plus adult moths, was determined for each replicate. Parasitism data were analyzed separately for the 50 and 9% interplanted orchards. Chi-square tests (SAS Institute 2001) were used to test for the presence of nectar effects on percentage parasitized larvae due to the inability to transform the data to fit assumptions of parametric statistics.

Fruit Injury Evaluation. This experiment was done to test the hypothesis that the presence of nectar sources in the orchard reduces the amount of injury to apple fruit by insect pests. Fruit were harvested at maturity for evaluation of insect injury in the interplanted and matching apple monoculture controls in 2005 and 2006. Twenty fruit from each of 15 randomly selected apple trees of each cultivar in the 50% interplanted and their control orchards were harvested. In the 9% interplanted orchard and its control, 10 fruit were harvested from each of 20 randomly selected apple trees of each cultivar. Fruit were placed in cold storage and evaluated within a week of harvest for both external and internal injury. Injury was attributed to a specific species or to a category of species when the type of injury could not be distinguished among species. Insects responsible for fruit injury were plant bug, primarily Lygus lineolaris (Palisot de Beauvois); Pentatomidae, primarily Euschistus servus (Say); internal worms, Cydia pomonella (L.) and Grapholita molesta (Busck) combined; Grapholita prunivora (Walsh); leafrollers, P. idaeusalis and other Tortricidae; other Lepidoptera; European apple sawfly, Hoplocampa testudinea (Klug); plum curculio, Conotrachelus nenuphar (Herbst); San Jose scale, Quadraspidiotus perniciosus (Comstock); apple maggot, Rhagoletis pomonella (Walsh); and rosy apple aphid, Dysaphis plantaginea (Passerini). Percentage fruit injury by each insect species or category was averaged per sample tree. Percentage of total insect injury per tree averaged across both years was analyzed with a chi-square test (SAS Institute 2001) to compare the injury from interplanted versus monoculture orchards for each category of injury separately. Poisson testing, and thus biased P values, of injury by individual species or category of species was conducted to investigate which were major contributors to any differences in total fruit injury. Chi-square analysis was used because the data could not be normalized with transformations.

Results

Laboratory Studies. Female G. floridanus adults lived twice as long in the presence of peach extraloral nectar and water (13.7 d) as with water alone (6.5 d; t = 73.9, df = 16, P < 0.001). Parasitism of tufted apple bud moth by G. floridanus also was increased by the presence of extraloral nectar. Parasitism for larvae with nectar (36.7 ± 4.0%) was significantly greater (t = 2.55, df = 21, P = 0.035) than for larvae in water-only treatments (24.3 ± 4.7%).

Point Source Attraction. More than triple the number of parasitoids were found on potted peach trees than on potted apple trees, whether or not the peach trees had extraloral nectar glands (F = 12.99, df = 2, 189, P < 0.0001) (Fig. 1). However, the apple trees immediately adjacent to the potted trees showed no statistical difference in abundance of parasitoids related to the type of potted tree or presence of nectar glands with an average of 10–13 parasitoids per trap (F = 1.00, df = 2, 765, P = 0.3539). Significantly more parasitoids were captured on the side of the trap facing away from all potted trees (15.2) than toward the potted trees (9.2) on the adjacent orchard trees (F = 41.53, df = 1, 766, P < 0.0001). Parasitism rates varied from 34 to 58% with no statistical differences (p = 4.685, df = 2, 189, P = 0.096) among the three treatments. Recovery of sentinel larvae was 44%.

Distance Attraction. There were significantly more parasitoids on the center cluster of potted peach trees than on apple trees at any distance from the source of extraloral nectar (F = 55.67, df = 3, 516, P < 0.0001) (Fig. 2). There was no association between the num-
number of parasitoids and the distance from the potted peach trees (Fig. 2). There were also significantly more parasitoids (*t = 4.98, df = 488, P < 0.0001*) on the side of the traps facing away from the potted peach trees (35.2 per trap) than facing toward the peach trees (25.2 per trap). Percentage of parasitism was highly variable, ranging from 0 to 65%. Combining all replicates, there was no effect of distance from the source of extraloral nectar on parasitism rate (*χ² = 2.4211, df = 2, P = 0.2950*). Recovery of sentinel larvae was 54%.

**Nectar Concentration.** There was no difference in parasitism rates between either the 50% interplanted apple orchard and its control (*χ² = 0.2560, df = 1, P = 0.6129*) or the 9% interplanted apple orchard and its control (*χ² = 1.1084, df = 1, P = 0.2924*). Recovery of sentinel larvae was 25% in 2004, 55% in 2005, and 40% in 2006.

**Fruit Injury Evaluation.** Only Granny Smith had a significant difference in percent total insect damage to fruit with more damaged fruit from the monoculture than the interplanted orchard (Table 1). Significant differences (*P < 0.05*, biased) in fruit injury between the interplanted and monoculture orchards were found for six of the insect species or species category for at least one cultivar (Table 1). Of the significant differences only injury caused by pentatomids and *Q. pertinax* were consistently significantly different in more than one cultivar (Table 1). Pentatomid and *Q. pertinax* injury were significantly more severe in the monoculture than in the orchards interplanted with peach trees producing extraloral nectar. Internal worm and *C. necialis* injury were significantly greater for two of the cultivars in the interplanted orchard but significantly greater in the monoculture orchard for a third cultivar. Injury from *L. lineolaris* was significantly different for two cultivars but differences were not consistent between treatments. Injury from *R. pomonella* was low and significantly different for only one cultivar.

**Discussion**

*G. floridanus* benefited in the laboratory from feeding on peach extraloral nectar with increased longevity and parasitism rates. The ability of the parasitoid to increase vigor from feeding on an alternative food resource supports our hypothesis that extraloral nectar increases parasitoid fitness. This is a similar response as shown by other parasitoids (Shearer and Atanassov 2004; Lee and Heimpel 2008) and predators (Limburg and Rosenheim 2001, Taylor and Pfannenstiel 2008). It is especially important for synovigenic species, such as *G. floridanus*, to feed as adults so they can continue to produce eggs throughout adult life (Godfray 1994).

Field studies, however, did not reflect the results from the laboratory. We did not detect any increase in parasitism rates as a result of the presence of peach extraloral nectar. In our field studies we used sentinel larvae to measure parasitism rates, a method found to be a good measure of actual parasitism (Savary et al. 2007). Rather than concentrating large numbers of larvae at one location as done by Savary et al. (2007), we placed two larvae per tree spread across the orchard to minimize bias from an unrealistically high population concentration. There are several possible reasons for not detecting a difference in parasitism rates from the addition of extraloral nectar in orchards. First, we do not know whether carbohydrate food is a limiting factor for tufted apple bud moth parasitoids in the orchard. Second, the dominant parasitoid, *G. floridanus*, feeds on hosts (C.R.M., unpublished data) and therefore in the orchard may not be lacking in food resources. Third, interactions among the many tortricids (Brown et al. 1988), their parasitoids, and hyperparasitoids (Biddenger et al. 1994) in and surrounding orchard ecosystems in eastern North
Table 1. Apple harvest evaluation comparing mean percent damaged fruit by insects and damage categorized as to particular species or species group for 2005 and 2006; data are reported only where there were significant differences \( (\chi^2) \) between interplanted with peaches producing extraloral nectar (I) and apple monoculture (M).

<table>
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<tr>
<th>50% interplanted</th>
<th>9% interplanted</th>
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<tr>
<td>Empire</td>
<td>Granny Smith</td>
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<tr>
<td>I</td>
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<tr>
<td>Total insect damage</td>
<td>86.4</td>
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<tr>
<td>Lygus lineolaris</td>
<td>15.0</td>
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<tr>
<td>Pentatomids</td>
<td>5.9</td>
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<tr>
<td>Internal worms</td>
<td>16.58**</td>
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<tr>
<td>C. nemaphur</td>
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<td>Q. perniciosus</td>
<td>39.8</td>
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<tr>
<td>R. pomonella</td>
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* Significantly higher damage than matching pair within cultivar, \( P < 0.05 \).

** Significantly higher damage than matching pair within cultivar, \( P < 0.01 \).

America may mask any increase in parasitism rate that may have occurred. Field studies showed that Hymenopteran parasitoids as a group did respond to the presence of peach trees within the apple orchard. Numbers of parasitoids were higher on traps in potted peach trees than in potted apple trees (Fig. 1). The high abundance of parasitoids on both peaches with and without extraloral nectar suggests that the higher number of parasitoids is a result of attraction rather than just an increase in residence time on peach trees. It did not seem, however, that nectar was the focus of parasitoid attraction. The majority of peach trees grown in the Mid-Atlantic region produce extraloral nectar, so it may be that parasitoids frequenting orchards may have learned to associate peach volatiles with the presence of nectar.

The lack of an increase in tufted apple bud moth parasitism in apple orchards with either 9% or 50% interplanting with peaches bearing extraloral nectar leads us to reject the overall hypothesis of this study, that the provision of nectar in an apple orchard increases biological control of apple pests. It is possible that the scale of these experiments was too small and the natural range of resource foraging by G. floridanus is greater than the distance between experimental and control plots as in the cabbage system (Lee and Heimpel 2005). Apple orchards are also very complex ecosystems, and the addition of extraloral nectar sources may have affected interactions beyond the one hypothesized. Therefore, we collected data on numerous other response variables within the larger study to more fully evaluate the effects of introducing extraloral nectar into the apple orchards. In previous reports, we presented the results of studies on biological control of two aphid species, D. plantaginea (Brown and Mathews 2007) and Aphis spireaola (Patch) (Brown and Mathews 2008). In both studies, we found a positive effect on the predator Harmonia axyridis (Pallas) (Coleoptera: Coccinellidae) associated with the presence of nectar but rates of biological control were not increased. For D. plantaginea, a high concentration of nectar (50% of the orchard interplanted with peaches) resulting in an interference with biological control with lower mortality rates than the lower concentration (9% interplanted orchard) (Brown and Mathews 2007). A laboratory test with A. spireaola also indicated a possible interference of biological control by H. axyridis with a high density of nectar sources (Spellman et al. 2006).

The harvest evaluation data measured the response of the apple ecosystem to the addition of peaches with extraloral nectar on all insect injury to apple fruit. The reduced fruit injury by pentatomids and Q. perniciosus indicates the experimental addition of peach trees with extraloral nectar did have a positive impact for fruit production. Both pentatomids (Ehler 2002) and Q. perniciosus (Flanders 1960) have effective parasitoids that are capable of providing complete or partial population regulation. The reduction in damage from these insects cannot, however, be attributed to biological control by higher parasitism rates with any certainty. Only a third of the pest suppression provided by ecosystem services is attributable to insect provided biological control (Losey and Vaughan 2006). There are many other ecosystem services by which addition of biodiversity to an ecosystem can lead to reduction in pest damage (Fiedler et al. 2008). Interplanted peach trees may well be affecting more ecosystem services within the apple orchard than biological control.

By collecting data on fruit injury we were able to document a reduction in damage of two pests by the interplanting of peach trees with extraloral nectar into apple orchards. Without information on the response of yield quality we would have concluded that the experimental addition of peaches had no effect on insect pest injury. But, the yield data showed that pentatomids and scales responded with decreased injury, through an as yet undetermined mechanism, from the experimental manipulation. Injury by internal worms and C. nemaphur in the presence of interplanted peach trees will have to be further examined and a cost–benefit analysis of the habitat manipulation is needed before recommendations can be made. It seems promising, however, that pest management in apple ecosystems can be enhanced by increasing its biodiversity with the addition of peach trees with extraloral nectar.
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