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Quality Over Quantity: Buffer Strips can be Improved with Select Native Plant Species

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Abstract

Native plants attractive to beneficial insects may improve the value of buffer strips by increasing biodiversity and enhancing the delivery of insect-derived ecosystem services. In a 2-yr field experiment, we measured the response of insect communities across nine buffers that varied in plant diversity. We constructed buffers with plants commonly found in buffers of USDA-certified organic farms in Iowa (typically a single species), recommended for prairie reconstruction, or recommended for attracting beneficial insects. We hypothesized that the diversity and abundance of beneficial insects will be 1) greatest in buffers composed of diverse plant communities with continuous availability of floral resources, 2) intermediate in buffers with reduced species richness and availability of floral resources, and 3) lowest in buffers composed of a single species. We observed a significant positive relationship between the diversity and abundance of beneficial insects with plant community diversity and the number of flowers. More beneficial insects were collected in buffers composed of species selected for their attractiveness to beneficial insects than a community recommended for prairie restoration. These differences suggest 1) plant communities that dominate existing buffers are not optimal for attracting beneficial insects, 2) adding flowering perennial species could improve buffers as habitat for beneficial insects, 3) buffers can be optimized by intentionally combining the most attractive native species even at modest levels of plant diversity, and 4) plant communities recommended for prairie reconstruction may not contain the optimal species or density of the most attractive species necessary to support beneficial insects from multiple guilds.

Keywords

Habitat management, Floral provisioning, Biodiversity-ecosystem function, Pollination, Biological control

Disciplines

Biodiversity | Entomology | Terrestrial and Aquatic Ecology

Comments

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Quality Over Quantity: Buffer Strips Can be Improved With Select Native Plant Species

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ABSTRACT Native plants attractive to beneficial insects may improve the value of buffer strips by increasing biodiversity and enhancing the delivery of insect-derived ecosystem services. In a 2-yr field experiment, we measured the response of insect communities across nine buffers that varied in plant diversity. We constructed buffers with plants commonly found in buffers of USDA-certified organic farms in Iowa (typically a single species), recommended for prairie reconstruction, or recommended for attracting beneficial insects. We hypothesized that the diversity and abundance of beneficial insects will be 1) greatest in buffers composed of diverse plant communities with continuous availability of floral resources, 2) intermediate in buffers with reduced species richness and availability of floral resources, and 3) lowest in buffers composed of a single species. We observed a significant positive relationship between the diversity and abundance of beneficial insects with plant community diversity and the number of flowers. More beneficial insects were collected in buffers composed of species selected for their attractiveness to beneficial insects than a community recommended for prairie restoration. These differences suggest 1) plant communities that dominate existing buffers are not optimal for attracting beneficial insects, 2) adding flowering perennial species could improve buffers as habitat for beneficial insects, 3) buffers can be optimized by intentionally combining the most attractive native species even at modest levels of plant diversity, and 4) plant communities recommended for prairie reconstruction may not contain the optimal species or density of the most attractive species necessary to support beneficial insects from multiple guilds.

KEY WORDS habitat management, floral provisioning, biodiversity–ecosystem function, pollination, biological control

The diversity and abundance of beneficial insects are positively influenced by plant-derived resources such as nectar, pollen, nesting substrates, and overwintering sites surrounding cultivated land (Westrich 1996, Elliott et al. 2002, Steffan-Dewenter et al. 2002, Landis et al. 2005, Klein et al. 2007, Zhang et al. 2007, Kwaiser and Hendrix 2008, Tschardt et al. 2008, Wackers et al. 2008, Le Féon et al. 2011). Patches of noncrop vegetation within agricultural landscapes can provide these resources, allowing beneficial insects to persist near agricultural fields before, during, and after periods when insect-derived ecosystem services are provided to annual crops (for reviews, see Landis et al. 2000, Bianchi et al. 2006, Isaacs et al. 2009). Plant resources are exploited at varying times and levels across different guilds of beneficial insects (pollinators, predators, and parasitoids), making the season-long availability of noncrop vegetation an important component of agricultural landscapes.

A loss of native plant diversity is evident across the midwestern United States. Historically, the state of Iowa was dominated ($\approx 79.5\%$) by tallgrass prairie ecosystems, but during the past 150 yr most of Iowa's native vegetation has been replaced by agricultural systems, and now $<0.1\%$ of native prairie remains in the state (Samson and Knopf 1994, Smith 1998). In general, such a loss of plant diversity in an agricultural landscape reduces the resources required by beneficial insects to survive and deliver ecosystem services to surrounding crops (Landis et al. 2005). Reconstruction of prairie plant communities in agricultural landscapes can conserve beneficial insects by increasing the amount of perennial habitat surrounding annual cropping systems. Many of the perennial plant species found in prairies are attractive to beneficial insects (Fiedler and Landis 2007a, Frank et al. 2008, Tuell et al. 2008), although variation exists in the attractiveness to insects among individual plant species. Species composition of the plant community likely influences the extent to which reconstructed prairie can contribute to the conservation of beneficial insects and delivery of insect-derived ecosystem services (Fiedler and Landis 2007b, Tuell et al. 2008, Isaacs et al. 2009).

Buffer strips are typically recognized for their role in soil and water conservation practices (e.g., grass

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filter strips, riparian buffers; Clark and Reeder 2007). Recently, buffer practices have been incorporated into requirements for organic production systems. Requirement § 205.202 ([USDA–NOP] United States Department of Agriculture–National Organic Program 2009) states that buffers are required of organic producers seeking certification from the USDA when organically managed land is adjacent to land not under organic management. The stated purpose of this mandatory buffer zone is to prevent the unintended application of a prohibited substance (e.g., pesticide and pollen from genetically modified crops) to the crop or contact with a prohibited substance applied to adjoining land that is not under organic management (USDA–NOP 2009). There are no specifications in this requirement regarding the composition of vegetative buffer zones. Reconstructing native perennial plant communities in buffer zones may increase biodiversity and ecosystem services, improving the value of buffers.

Our goal is to develop best management practices for designing and establishing perennial multi-species buffers that are compatible with agricultural landscapes and attractive to beneficial insects. In a simple garden-variety experiment conducted over 2 yr, we compared the response of insect communities to buffers composed of individual plant species commonly found in buffers on USDA-certified organic farms in Iowa, and buffers composed of multiple perennial plants. We included a buffer composed of plants recommended for prairie reconstruction, and an equally diverse buffer composed of prairie plants selected for their attractiveness to beneficial insects. Altogether, we constructed nine buffer treatments with increasing plant diversity and availability of floral resources. We hypothesized that the diversity and abundance of beneficial insects in these buffers would be 1) greatest in buffers with diverse plant communities with continuous availability of floral resources, 2) intermediate in buffers with reduced plant species richness and availability of floral resources, and 3) lowest in buffers composed of a single species.

Materials and Methods

Site Description and Experimental Design. The study site was established at Iowa State University's Field Extension Education Laboratory (FEEL) located in Boone County, IA (42° 00.318' N, 93° 47.272' W). The site is a 17-ha demonstration farm divided into multiple plots devoted to crop-related research. Adjacent fields and the surrounding landscape were composed of corn and soybean crops. On 23 June 2009, we constructed 36 garden-style plots measuring 2 by 2 m bordered by 5- by 15-cm pressure-treated lumber. These plots were distributed along a 55- by 24-m bare-soil field in a grid formation of four blocks (oriented west to east) with nine plots per block. Nine buffer treatments were designed with plant communities that vary in diversity and complexity (described below). Each treatment was replicated four times and

randomly assigned to plots using a randomized complete block design.

Buffer Treatments. We constructed nine different buffers to test our hypotheses regarding the impact of plant diversity on the diversity and abundance of beneficial insects. The nine buffer treatments were constructed from plants used in buffers of certified organic farms in Iowa (simple buffers), recommended for prairie reconstruction (diverse buffers), or recommended for attracting beneficial insects (diverse and forb-only buffers).

Simple Buffers. Input from organic farmers was used to develop a subset of four buffer treatments. In 2008, we surveyed organic farmers who were certified by the top three certifying agencies in Iowa (Midwest Organic Services Association, Inc., Organic Crop Improvement Association, and the Iowa Department of Agriculture and Land Stewardship). From this survey (data not shown, R. Cox), we determined most organic farms (72%) had perennial grasses or a crop species in their buffer strips. These data informed which plant species were used in the four buffer treatments composed of a single plant species (hereafter referred to collectively as "simple buffers"). Individual plant species or cultivars were selected using the following considerations: 1) crop and noncrop species used commonly by organic producers who completed our survey, 2) species compatible with local agricultural field conditions (e.g., full-sun, noninvasive), and 3) species that have ecological and economic benefits in addition to potentially conserving beneficial insects (e.g., erosion control, crops harvested and sold as conventionally produced, and species that may be used or sold as forage). The four simple buffer treatments are monocultures of switchgrass (*Panicum virgatum* L.), alfalfa (*Medicago sativa* L.), willow (*Salix matsudana* Koidzumi), and corn (*Zea mays* L.).

Diverse Buffers. We established two buffer treatments as diverse plant communities (hereafter referred to collectively as "diverse buffers") to test the hypothesis that buffers composed of multiple plant species would attract a more diverse and abundant community of beneficial insects than simple buffers. Diverse plant communities were composed of a mixture of grasses and forbs that met the following criteria: 1) perennial species native to the north-central region of the United States; 2) species that, in combination, produce flowers throughout the growing season; 3) species with low to moderate aggressive growth; and 4) species commercially available in local genotypes (ecotypes).

We established one diverse buffer treatment based on recommendations from the Iowa Natural Resources Conservation Service ([USDA–NRCS] United States Department of Agriculture–Natural Resource Conservation Service 2010; Table 1). This treatment is referred to as the "CP-IA buffer," as the species in this buffer were identified for conservation targeting restoration of rare and declining habitats (e.g., Iowa's native tallgrass prairie). Goals of this practice include increasing plant diversity and providing habitat and food for wildlife. The description

Table 1. Species selected for the CP-IA buffer and their associated characteristics

Common name ^a	Scientific name	Bloom time ^b	Growth habit ^c
Spotted geranium	<i>Geranium maculatum</i> L.	May–June	FB
Pale purple coneflower	<i>Echinacea pallida</i> (Nutt.) Nutt.	June–July	FB
Blackeyed susan	<i>Rudbeckia hirta</i> L.	June–Aug.	FB
Smooth oxeye	<i>Heliopsis helianthoides</i> (L.) Sweet	June–Aug.	FB
Culver's root	<i>Veronicastrum virginicum</i> (L.) Farw.	June–Aug.	FB
Purple prairie clover	<i>Dalea purpurea</i> Vent.	June–Aug.	LG-FB
Canada wildrye	<i>Elymus canadensis</i> L.	July–Sept.	CS-GR
Sideoats grama	<i>Bouteloua curtipendula</i> (Michx.) Torr.	July–Sept.	WS-GR
Big bluestem	<i>Andropogon gerardi</i> Vitman	Aug.–Sept.	WS-GR
Indiangrass	<i>Sorghastrum nutans</i> (L.) Nash	Aug.–Sept.	WS-GR
Rough dropseed	<i>Sporobolus clandestinus</i> (Biehler) Hitchc.	Aug.–Sept.	WS-GR
Prairie sage	<i>Artemisia ludoviciana</i> Nutt.	Aug.–Oct.	SS
Short's aster	<i>Symphotrichum shortii</i> (Lindl.) G.L. Nesom	Aug.–Oct.	FB
Stiff goldenrod	<i>Oligoneuron rigidum</i> (L.) Small	Aug.–Oct.	FB

^a The CP-IA buffer includes 14 native perennial species: five grasses, eight forbs, and a shrublet, which are a subset of species selected from conservation practice CP25, that in combination, bloom throughout the season.

^b Species are ordered by bloom periods (earliest–latest for Iowa) when conspicuous flowers or inflorescences are present. The duration of flowering can be from 3 wk to 3 mo depending on the species and environmental conditions.

^c Growth habit codes indicate functional groups: FB, forb/herb; LG-FB, leguminous forb; CS-GR, cool-season graminoid; WS-GR, warm-season graminoid; SS, sub shrub.

also indicates healthy prairie habitats can be a source of flowers for pollinating insects (USDA–NRCS 2010), but it is unclear how attractive this buffer would be for beneficial insects from multiple guilds. This buffer was not designed with the primary goal of increasing the diversity and abundance of bees and natural enemies, and its ability to do so has not yet been tested.

A second, diverse buffer treatment was established to test the hypothesis that diverse plant communities can be optimized to attract beneficial insects. This buffer was designed to increase the diversity and abundance of bees and natural enemies. We selected a combination of plant species identified by Fiedler and Landis (2007a) and Tuell et al. (2008), who identified species that were highly attractive to natural enemies and bees and exhibited relatively low attractiveness to arthropod pests. Twelve species were selected for the “MSU Best Bet” buffer (honoring the work conducted at Michigan State University [MSU

2012]; details available at nativeplants.msu.edu; Table 2).

Forb-Only Buffers. Three buffer treatments were established with only forbs (Table 3) to assess the response of beneficial insects to plant communities with a reduction in plant species richness and resource availability. We hypothesized that beneficial insect diversity and abundance will be intermediate in these forb-only buffers. The selection criteria for these species were consistent with (1–4) of the diverse buffers, using only the most attractive forbs from the MSU Best Bet buffer. The most species rich of these treatments, referred to as “MSU5,” contained five species of forbs, which provided flowering resources from two or more species blooming throughout the growing season. Treatments referred to as “MSU3” and “MSU2” were systematic reductions of the MSU5 treatment, designed by reducing the phenological overlap of species in bloom.

Table 2. Species selected for the MSU Best Bet buffer and their associated characteristics

Common name ^a	Scientific name	Bloom time ^b	Growth habit ^c
Canadian anemone	<i>Anemone canadensis</i> L.	May–June	FB
Meadow zizia ^d	<i>Zizia aptera</i> (A. Gray) Fernald	May–June	FB
Pinnate prairie coneflower	<i>Ratibida pinnata</i> (Vent.) Barnhart	June–Aug.	FB
Swamp milkweed	<i>Asclepias incarnata</i> L.	June–Aug.	FB
Switchgrass	<i>Panicum virgatum</i> L.	July–Aug.	WS-GR
Canada wildrye	<i>Elymus canadensis</i> L.	July–Sept.	CS-GR
Common boneset	<i>Eupatorium perfoliatum</i> L.	July–Sept.	FB
Cup plant	<i>Silphium perfoliatum</i> L.	July–Sept.	FB
Prairie ironweed ^d	<i>Vernonia fasciculata</i> Michx.	July–Sept.	FB
Little bluestem	<i>Schizachyrium scoparium</i> (Michx.) Nash	Aug.–Oct.	WS-GR
New England aster	<i>Symphotrichum novae-angliae</i> (L.) G.L. Nesom	Aug.–Oct.	FB
Smooth blue aster	<i>Symphotrichum laeve</i> (L.) Á. Löve & D. Löve	Aug.–Oct.	FB

^a The MSU Best Bet buffer includes 12 native perennial species: three grasses and nine forbs, selected based on those individually rated “Best” for relative attractiveness to either (or both) natural enemies and bees in evaluations by Fiedler and Landis (2007) and Tuell et al. (2008). Selection was further restricted to Iowa ecotypes that, in combination, bloom throughout the season.

^b Species are ordered by bloom periods (earliest–latest for Iowa) when conspicuous flowers or inflorescences are present. The duration of flowering can be from 3 wk to 3 mo depending on the species and environmental conditions.

^c Growth habit codes indicate functional groups: FB, forb/herb; CS-GR, cool-season graminoid; WS-GR, warm-season graminoid.

^d *Vernonia missurica* and *Zizia aurea* used by Fiedler and Landis (2007) were not available as plugs through our local provider and were replaced with *V. fasciculata* and *Z. aptera*; similar species in the same genus.

Table 3. Species included in forb-only buffers

Common name ^a	Scientific name ^b	Buffer treatments		
		MSU5	MSU3	MSU2
Meadow zizia	<i>Zizia aptera</i>	X	X	X
Swamp milkweed	<i>Asclepias incarnata</i>	X	X	
Pinnate prairie coneflower	<i>Ratibida pinnata</i>	X		
Cup plant	<i>Silphium perfoliatum</i>	X	X	X
New England aster	<i>Symphotrichum novae-angliae</i>	X		

^a Forbs from the MSU Best Bet buffer were selected to create three additional treatments. The planting density of each forb-only buffer remained the same as the diverse buffers, but species richness was reduced. Bloom periods and growth habits are as in Table 2. An "X" indicates species present in each forb-only buffer.

^b Authors for species as in Table 2.

Plant Establishment. Switchgrass plugs (1-yr-old plants, Ion Exchange Inc., Harpers Ferry, IA) were transplanted by hand on 21 April 2010. Plugs were planted at a density of one plug per 929 sq cm resulting in 25 plants per replicate plot. Plugs were positioned 15 cm from the plot borders on all sides, and 30 cm spacing was maintained between plants.

Alfalfa seed was purchased locally (Brekke's Town and Country Store, Ames, IA) and sown on 9 April 2010. Seed was hand broadcast using the standard rate of 8–9 kg per ha, resulting in 0.009 kg of seed per replicate plot. Owing to the small amount of seed being used, seeds for each plot were weighed, portioned, and combined with coarse sand to add bulk to the material to ensure an even distribution when broadcasting.

Willow cuttings were taken from established willow stands (Small Potatoes Farm, Minburn, IA) in February 2010. Once the root mass was adequately developed, shrubs were obtained from the farm and transplanted on 21 April 2010. Willow shrubs ranging from 61 to 91 cm in height were planted at a density of three shrubs per replicate in a triangle formation with 122 cm spacing between each shrub.

Corn seed (DEKALB DKC 61–72 Roundup Ready Corn; Monsanto Co., St. Louis, MO) was sown by hand on 7 May 2010 and 11 May 2011 with three rows per replicate plot and 15-cm plant spacing and 76-cm row spacing, resulting in a density of 35 plants per replicate plot. In 2010, corn plants that did not emerge were replanted on 1 June 2010.

Plugs (1-yr-old plants, Ion Exchange Inc., Harpers Ferry, IA) were used to establish diverse and forb-only plant communities. All plugs were transplanted by hand on 16 September 2009. These five buffer treatments (MSU2, MSU3, MSU5, CP-IA, and MSU Best Bet) were planted earlier than other treatments to allow time required for perennial species to establish. Plugs were planted at a density of 25 per plot, and individual species placement within plots was kept the same across replications to reduce within-treatment variation among replicates. Plugs were positioned 15 cm from the plot borders on all sides, and 31-cm spacing was maintained between plants.

Field and Plot Maintenance. A 4-m distance was maintained between each plot in all directions to allow for mowing between plots. All plots were mulched once in late October 2009, with clippings of clean oat straw to control weeds and protect establishing seedlings (plugs) from frost and animal damage. The straw was removed during early April 2010 before the establishment of simple buffer treatments. Annual ryegrass (*Lolium multiflorum* Lamarck) was sown as ground cover between plots on 24 May 2010 and mowed throughout the sampling period. Plots were not mulched with straw after the 2010 growing season, as a thatch layer from first-year plant material was left in plots. In both years, weeds were removed between and within plots to maintain species composition with special attention to weed removal immediately before insect sampling.

Plant Measurements. Plant diversity, percent ground cover, canopy height, and flower abundance were measured in each buffer treatment to determine whether plant characteristics account for variation in beneficial insect diversity and abundance. The number of plants and plant species per plot were counted and Simpson's diversity index (1/D) was calculated for each plot (Simpson 1949). Analyses were based on final measurements taken in August 2010 and 2011 to represent the maximum end-of-season plant diversity and to account for the annual establishment of corn plants. For each year, resulting diversity values were summed among replicates and mean plant diversity was calculated per buffer treatment. Simpson's diversity indices were calculated using the "vegan" package version 2.0–1 in R version 2.14.1 (Oksanen et al. 2011, R Development Core Team 2011).

Buffer treatments were designed to achieve variation in the amount and timing of floral resources. To determine whether we achieved this variation, the number of flowers was counted two times per month, coinciding with arthropod collection. Flower abundance was measured for plots containing conspicuous flowers; therefore, corn and switchgrass were not measured. The bloom period of willows preceded the annual establishment of corn plants, and therefore, our sampling period, so willows also were excluded from floral measurements.

For buffer treatments with conspicuous flowers, flower abundance was measured by counting the number of individual open flowers on each plant. Individual flowers were defined as flower heads for Asteraceae spp. and Geraniaceae spp., umbels per cluster for Asclepiadaceae spp., solitary flowers for Ranunculaceae spp., and spikes and racemes for Scrophulariaceae and Fabaceae spp. For each year, flower data were summed across the six sample dates among replicates, and mean flower abundance was calculated based on the total number of observations ($n = 24$) per buffer treatment.

The height of each plant was measured to the tallest point. Mean canopy height was calculated as the sum of all plant heights per plot over the total plant heights of each buffer treatment. Five random subsamples per plot were taken to measure percent ground cover by

tossing a 31- by 31-cm quadrat into plots and visually estimating the proportion of ground covered by vegetation within each quadrat. Percentages for each toss were estimated by two different individuals and averaged over the total number of estimates recorded in each buffer treatment. Analyses were based on final measurements taken in August 2010 and 2011, to represent the maximum, end-of-season height and ground cover and to account for the annual establishment of corn plants. For each year, resulting values were summed among replicates, and means for canopy height and ground cover were calculated per buffer treatment ($n = 4$).

Arthropod Collection, Identification, and Guild Assignment. Arthropod (insect and spider) communities were sampled in each plot throughout the 2010 and 2011 growing season (June, July, and August). We used vacuum sampling methods adapted from Fiedler and Landis (2007a). A fine mesh white paint strainer was placed over the air intake on a gas-powered leaf blower (Troy-Bilt, model no. TB320BV), and vegetation in each plot was vacuumed for 30 s while moving continuously around each plot to contact the foliage and flowers on all sides. The mesh strainer with the sample was then removed and placed into a clear plastic resealable bag. An unused clean mesh strainer was used for sampling subsequent plots. Vacuum sampling occurred during the first and third week of each month during the sampling period with no <12 d between sampling events. To ensure high insect activity and consistency among samples, vacuum sampling was restricted to mid-day during favorable weather conditions (warm sunny days with cloud cover <30% and wind gusts below 5 mph). After each sampling event, insects were transported to the lab and frozen until processed. Voucher specimens were deposited in the Department of Entomology, Insectary at Iowa State University, Ames, IA.

When possible, insects were identified to species. Spiders were identified to order (Araneae). When species identification could not be resolved, individuals were identified to the lowest taxonomic unit possible or organized into morphospecies, and given a unique identifier for reference and classification of duplicates. Following identification, individuals were grouped into guilds: herbivores, predators, parasitoids, pollinators, detritivores, fungivores, and "other" based on species accounts described in identification keys and reviewed literature. The group referred to as "other" includes species with nonfeeding adults, blood feeders, and unresolved feeding habits. Insects occupying different guilds in different stages of their life cycles (i.e., herbivores, predators, and parasitoids) were classified based on feeding behaviors of their immature stages. For this study, the pollinator guild was defined as managed *Apis mellifera* L. and wild, non-*Apis* bee species.

Initially, we described the species composition of the entire insect community among buffer treatments to determine differences in overall diversity compared with diversity within guilds. Further analyses focused on the diversity and abundance of beneficial guilds

that provide either biological control (a combination of predators and parasitoids) or pollination (bees).

To describe the diversity of beneficial insects, we calculated species richness as the number of taxonomic units in each vacuum sample. For each year, the resulting values were summed across the six sampling dates among replicates, and mean species richness was calculated based on the total number of observations ($n = 24$) per buffer treatment. Species richness estimates for bees and natural enemies were restricted to the number of taxonomic units identified to species or classified as morphospecies. Bee and natural enemy taxa with undetermined identifications and spiders were omitted from measures of species richness owing to unresolved species-level identifications. However, we did include spiders in all estimates of the abundance of natural enemies. Diversity indices of species richness were calculated using the "vegan" package version 2.0-1 in R version 2.14.1 (Oksanen et al. 2011, R Development Core Team 2011).

To describe the abundance of beneficial insects, we calculated the number of individuals in each vacuum sample. For each year, the resulting values for each sample were summed across the six sampling dates among replicates, and mean abundance was calculated based on the total number of observations ($n = 24$) per buffer treatment. Mean abundance was calculated separately for herbivores, predators, parasitoids, pollinators, detritivores, and fungivores for each treatment. All guilds were included to describe the proportion of the insect community comprised by each group. Analyses focused on bees and natural enemies of insect pests.

Statistical Analyses. A paired *t*-test was used to test for differences between expected and observed plant diversity (Simpson's diversity index, $1/D$) of each buffer treatment. For expected diversity, $1/D$ was calculated as if all species in each plot established as planned. This was compared with observed diversity, $1/D$ calculated for each plot based on species that actually established (PROC TTEST, SAS 9.2, SAS Institute 2008; $1/D$ calculated using the "vegan" package version 2.0-1 in R version 2.14.1, Oksanen et al. 2011, R Development Core Team 2011). We used ANOVA to test for variation among means for observed plant diversity, canopy height, percent ground cover, and flower abundance among buffer treatments. This model included treatment (nine buffer treatments) and block (four replicate plots) as fixed effects and the interaction of treatment and block (PROC GLM, SAS 9.2, SAS Institute 2008). When significant differences in plant measurement data were detected, a post hoc mean comparisons test was performed using least significant differences (LSD), Student-Newman-Kuels (SNK) procedure ($\alpha = 0.05$; PROC GLM, 9.2, SAS Institute 2008). Ground cover data were arcsine square root transformed before analysis, and transformed data were used to determine significant differences, and untransformed means are presented in results. Plant measurement data were analyzed separately for 2010 and 2011 to account for variation between years. Results of analyses pertaining to canopy

height, percent ground cover, and flower abundance, were reported separately by year, but values for plant diversity across treatments did not vary between years and are only reported once (using 2010 data) to represent both 2010 and 2011.

We tested multiple hypotheses related to the relationship between buffer treatments and insect diversity and abundance. All buffer treatments were included to test the null hypothesis that the diversity and abundance of insect communities did not vary among the nine different buffer treatments. Additional hypotheses pertained to a subset of the nine treatments. In all procedures described below, data were analyzed separately for 2010 and 2011 to account for variation between years.

We compared the species composition of insect communities (included species of all guilds) among buffer treatments using nonmetric multidimensional scaling (nMDS). Treatments were ordinated using the Bray–Curtis dissimilarity matrix and plotted in two dimensions. We used multi-response permutation procedures (MRPP) to test the null hypothesis of no difference among treatments. In addition, we fitted the abundance of insects in each guild as regressed vector arrows. Arrows point in the direction of increasing abundance for each guild, and arrow length indicates amount of proportional correlation with the ordination. The “vegan” package version 2.0–1 in R version 2.14.1 (Oksanen et al. 2011, R Development Core Team 2011) was used to conduct nMDS, MRPP, and vector fitting procedures.

We used ANOVA to test the null hypothesis of no difference in the diversity of bees and natural enemies among buffer treatments (PROC GLM, SAS 9.2, SAS Institute 2008). This model included treatment (nine buffer treatments) and block (four replicate plots) as fixed effects and the interaction of treatment and block as random effects. When significant differences in diversity data were detected, a post hoc mean comparison test was performed with the LSD SNK procedure ($\alpha = 0.05$) to identify differences (PROC GLM, SAS 9.2, SAS Institute 2008).

We used ANOVA to test the null hypothesis of no difference in the abundance of bees and natural enemies among buffer treatments. This model included treatment (nine buffer treatments), block (four replicate plots), and time (six sampling events) as fixed effects and the interaction of treatment and block as random effects (PROC GLM, SAS 9.2, SAS Institute 2008). The abundance of herbivores was also analyzed to determine whether buffer treatments vary in their attractiveness to herbivores, particularly pest species. When significant differences in abundance data were detected, a post hoc mean comparison test was performed using the LSD SNK procedure ($\alpha = 0.05$) to identify differences (PROC GLM, SAS 9.2, SAS Institute 2008).

We determined which plant characteristics explained the most variation in the diversity and abundance of bees and natural enemies using multiple linear regression analysis and Akaike’s Information Criterion for model selection, adjusted for sample size

(AIC_c; Burnham and Anderson 2002). For each year, explanatory variables included were plant diversity (Simpson’s diversity index, $1/D$), canopy height, percent ground cover, and flower abundance. Percent ground cover data were arcsine square root transformed before analysis, and transformed data were used to generate models. Response variables included the diversity and abundance of bees and natural enemies. We report the “best-fit model” (i.e., the model with the minimum AIC_c value) and “competing models” (i.e., any model for the same response variable having an AIC_c value with a difference less than two is considered strongly supported; Burnham and Anderson 2002). Models with differences in AIC_c values greater than two (compared with the best-fit model) were considered too weak to support these data and are not shown. Model selection was performed using the “AICcmodavg” package version 1.24 in R version 2.14.1 (R Development Core Team 2011, Mazerolle 2012).

Results

Plant Diversity. No significant differences were found between expected and observed mean plant diversity (Simpson’s diversity index, $1/D$) within our established buffer treatments ($P > 0.05$). As expected, we observed a significant difference in plant diversity among the nine buffer treatments ($F = 40.16$; $df = 8, 35$; $P < 0.0001$; Table 4). These differences were consistent with the desired treatments assigned to each plot.

Plant Measurements. The number of flowers among buffer treatments with conspicuous flowers increased from 2010 to 2011. The abundance of floral resources available per vacuum sampling event varied significantly across buffer treatments in 2010 ($F = 13.61$; $df = 5, 215$; $P < 0.0001$) and 2011 ($F = 12.86$; $df = 5, 215$; $P < 0.0001$; Table 4). The MSU Best Bet, MSU5, MSU3, and MSU2 buffer treatments had significantly more flowers in bloom per sampling event compared with the CP-IA buffer and alfalfa (Table 4). There were significant differences in canopy height and percent ground cover among buffer treatments in 2010 (canopy height: $F = 10.23$; $df = 8, 35$; $P < 0.0001$; ground cover: $F = 13.23$; $df = 8, 35$; $P < 0.0001$) and 2011 (canopy height: $F = 9.19$; $df = 8, 35$; $P < 0.0001$; ground cover: $F = 17.47$; $df = 8, 35$; $P < 0.0001$).

Insect Community Composition. Vacuum sampling yielded 14,632 insects in 2010 and 22,261 insects in 2011. Samples collected in 2010 were primarily composed of herbivores (59%), followed by beneficial insects composed of predators, parasitoids, and bees (28% pooled). Detritivores, fungivores, and “other” accounted for the remaining 13% of the total insect community. Herbivores remained the dominant guild in 2011, accounting for 73% of collected insects and the proportion of beneficial groups decreased to (17%) relative to the total. Detritivores, fungivores, and “other” accounted for the remaining 10% of the total insect community.

Table 4. Mean \pm SEM for plant characteristics measured among buffer treatments during 2010 and 2011

Buffer	Diversity ^a	2010			2011		
		Canopy ht (cm) ^b	Ground cover (%) ^c	Flower no. ^d	Canopy ht (cm) ^b	Ground cover (%) ^c	Flower no. ^d
Corn	1 \pm 0e	159 \pm 13b	20 \pm 4c	—	156 \pm 13b	18 \pm 4d	—
Willow	1 \pm 0e	135 \pm 46a	5 \pm 0.2c	—	297 \pm 49a	4 \pm 1d	—
Switchgrass	1 \pm 0e	115 \pm 10b	74 \pm 6a	—	119 \pm 10b	74 \pm 6ab	—
Alfalfa	1 \pm 0e	55 \pm 4b	85 \pm 3a	8 \pm 2b	60 \pm 4b	81 \pm 3a	9 \pm 3b
MSU2	2 \pm 0d	104 \pm 11b	37 \pm 11b	64 \pm 12a	115 \pm 21b	37 \pm 10c	70 \pm 13a
MSU3	3 \pm 0.1c	89 \pm 29b	45 \pm 4ab	52 \pm 13a	91 \pm 26b	47 \pm 4bc	58 \pm 15a
MSU5	5 \pm 0.1b	79 \pm 11b	68 \pm 6ab	30 \pm 7a	99 \pm 14b	71 \pm 6ab	31 \pm 7a
MSU Best Bet	12 \pm 0.3a	117 \pm 32b	53 \pm 5ab	67 \pm 14a	109 \pm 6b	54 \pm 6bc	68 \pm 14a
CP-IA	12 \pm 0.4a	77 \pm 15b	60 \pm 9a	23 \pm 4b	83 \pm 6b	61 \pm 9bc	24 \pm 4b

Means within columns followed by common letters are not significantly different at $P < 0.05$.

^a Plant diversity is the mean value of Simpson's diversity index (1/D), values increase as diversity increases. Diversity values were the same for both years and are reported once to represent both 2010 and 2011.

^b Canopy represent end-of-season canopy height measured in August data during 2010 and 2011.

^c Percent ground cover represents end-of-ground cover measured in August data in 2010 and 2011. Significant differences are based on arcsine square root transformed data; untransformed means are presented here.

^d Flower number is the mean abundance of flowers per buffer type per sampling event.

In both years, alfalfa treatments experienced outbreaks of the potato leafhopper, *Empoasca fabae* Harris (Hemiptera: Cicadellidae). This species was the most common herbivore in both 2010 (22% of all herbivores and 13% of the total community) and 2011 (47% of all herbivores and 35% of the total community). Leafhopper abundance in our experiment may not represent how outbreaks of *E. fabae* typically occur in an on-farm setting. Alfalfa would have been cut and harvested when *E. fabae* infestations occur (Lefko et al. 1999). We did not cut the alfalfa during this experiment, allowing populations of *E. fabae* to persist. Other than *E. fabae*, no other economically important pests were observed. When *E. fabae* is omitted, the recalculated ratios for each guild relative to the total are more similar between years (2010: 53% herbivores and 33% beneficial groups; 2011: 60% herbivores and 24% beneficial groups). The abundance of insects in

vacuum samples varied significantly by year for natural enemies ($F = 14.03$; $df = 1, 431$; $P < 0.0001$), bees ($F = 20.02$; $df = 1, 431$; $P < 0.0001$), and herbivores ($F = 13.52$; $df = 1, 431$; $P = 0.0001$). Owing to the variation in insect abundance by year, data were analyzed separately for 2010 and 2011.

We used nMDS ordination to show the configuration of treatments based on the species composition of insects (Fig. 1). Ordinations were plotted in two dimensions, and stress for the final solutions was 0.02 and 0.067 for 2010 and 2011, respectively; these values are considered ideal for species abundance data (Clarke 1993, McCune and Grace 2002). Based on the MRPP tests, the insect communities collected among buffer treatments were significantly different in 2010 ($A = 0.04$; $P < 0.001$) and 2011 ($A = 0.07$; $P = 0.009$). Vector arrows show the abundance of beneficial insects of multiple guilds is increasing in the directions of the

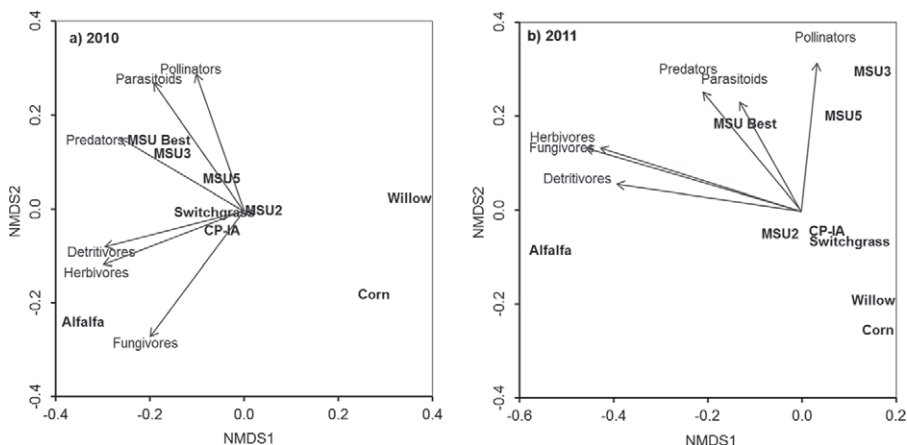


Fig. 1. Nonmetric multidimensional scaling ordinations (nMDS plots) of the species composition based on the Bray-Curtis dissimilarity indices for (a) 2010 and (b) 2011 samples depicting the configuration of treatments in relation to the community dissimilarity; treatments in proximity have a more similar species composition than treatments separated by greater distances. The plotted arrows indicate the insect guilds correlated with treatments, and the arrow points in the direction of the most rapid change in increasing abundances. Correlations were significant at $P \leq 0.05$.

Table 5. Total and mean ± SEM taxonomic units per buffer treatment for bees and natural enemies in 2010 and 2011

	Corn	Willow	Switch-grass	Alfalfa	MSU2	MSU3	MSU5	MSU Best Bet	CP-IA
Bee taxa									
Total ^a	1	2	3	6	13	14	13	18	14
2010 Mean ± SEM	0d	1 ± 0.6d	1 ± 0.7d	2 ± 0.9cd	5 ± 1.4bc	5 ± 1.6bc	7 ± 1.5b	10 ± 1.2a	6 ± 1.8b
2011 Mean ± SEM	0.3 ± 0.2b	0b	0b	1 ± 0.2b	4 ± 0.6a	4 ± 0.6a	2 ± 1.2ab	3 ± 1.2ab	1 ± 0.4ab
Natural enemy taxa									
Total ^a	37	32	50	58	50	51	59	57	57
2010 Mean ± SEM	17 ± 2b	10 ± 1b	36 ± 1a	43 ± 6a	36 ± 4a	38 ± 6a	40 ± 3a	48 ± 5a	45 ± 3a
2011 Mean ± SEM	16 ± 4d	15 ± 3d	25 ± 4cd	46 ± 4a	22 ± 0.6cd	28 ± 2bcd	36 ± 2abc	40 ± 5a	27 ± 2bcd

Means within columns followed by common letters are not significantly different at $P < 0.05$.

^aTotal refers to the total number of species/unique morphospecies within a guild summed across all samples collected in 2010 and 2011. Species captured in both years were only counted once for totals.

MSU Best Bet, MSU5, and MSU3 buffers. The insect communities in simple buffers, especially corn and willow, have the least number of shared species in comparison with all other buffer treatments.

Pollinator Diversity. We observed a bee community composed of 24 taxonomic units representing five families, with MSU Best Bet buffer collecting the most (18 taxonomic units). We found two to three times more bee species in diverse and forb-only buffers than in simple buffers (Table 5), although this relationship varied by year. During each year, we observed significant differences in bee diversity among buffer treatments. The mean number of bee species collected varied significantly across buffer treatments in 2010 ($F = 6.25$; $df = 8, 215$; $P = 0.0002$) and 2011 ($F = 5.73$; $df = 8, 215$; $P = 0.0004$). In 2010, we observed the most bee species within the MSU Best Bet buffer; in 2011 we did not observe significant differences among any of the treatments with multiple plant species (Table 5). Bee diversity was lowest in simple buffers composed of only one species. In 2010, no bees were captured in corn treatments, and in 2011, there were no bees captured in either willow or switchgrass treatments.

The majority of bees collected among buffer treatments were species native to North America. Exceptions include a few introduced species such as the honey bee (*A. mellifera*) and the alfalfa leafcutting bee, *Megachile rotundata* F., both found only in 2011. *Megachile rotundata* was observed only in the MSU Best Bet buffers while *A. mellifera* was observed in MSU5, MSU Best Bet, and CP-IA buffers. The majority of taxa (79%) we captured were ground-nesting bees, but at least one cavity-nesting species was represented in all families except Andrenidae. Ground-nesting species exhibit different levels of sociality ranging from annual eusocial (e.g., *Bombus* spp.), communal (*Agapostemon* spp.), solitary (*Melissodes* spp.), and variations thereof (Halictidae spp.). In contrast, cavity-nesting species are all solitary nesters (Packer et al. 2007). Most species collected among buffer treatments are considered common or locally abundant in our region (Michener 2000, Packer et al. 2007; see also Ascher and Pickering 2012 for geographic distribution maps).

Natural Enemy Diversity. We observed a natural enemy community composed of 87 taxonomic units representing 41 families. Overall, natural enemies

were most diverse in the MSU5 buffer, followed by alfalfa, the diverse buffers, and the other forb-only buffers, varying by nine or fewer species (Table 5). On a per plot basis, we found two to four times the mean number of taxa observed in plots with multiple plant species than corn or willow.

The mean number of species per plot varied significantly across buffer treatments in 2010 ($F = 10.22$; $df = 8, 215$; $P < 0.0001$) and 2011 ($F = 8.35$; $df = 8, 215$; $P < 0.0001$). In 2010, we observed significantly fewer natural enemy taxa within corn and willow treatments, but no significant differences were observed among the remaining treatments. In 2011, we observed significantly more natural enemy taxa within alfalfa and the MSU Best Bet buffers compared with the other treatments, excluding the MSU5 treatment, which had as many natural enemies as all treatments but corn and willow (Table 5).

Most natural enemies collected among buffer treatments are considered widely distributed and common across our region. During 2010, parasitoids accounted for a greater proportion of natural enemy taxa compared with predators (60% and 40%, respectively), and in 2011 parasitoids were slightly less dominant than predators (49% and 51%, respectively). Most of the natural enemy species captured were generalists such as *Orius insidiosus* (Say) (Hemiptera: Anthocoridae), *Nabis* spp. (Hemiptera: Nabidae), *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae), tachinid flies (Diptera: Tachinidae), and pteromalid wasps (Hymenoptera: Pteromalidae). Some of the natural enemies we observed are omnivorous (e.g., *Coleomegilla maculata* (DeGeer), syrphids flies, free-living adult parasitoids) and supplement their diet with plant-derived foods, such as pollen and nectar (Triplehorn and Johnson 2005). These taxa can be biological control agents of agronomic insect pests including the soybean aphid (*Aphis glycines* Matsumura; Rutledge et al. 2004, Costamagna et al. 2008), potato leafhopper (*E. fabae*; Östman and Ives 2003, Weiser Erlandson and Obrycki 2010), and European corn borer (*Ostrinia nubilalis* (Say) (Musser and Shelton 2003). In several studies, these natural enemies were positively associated with plant community diversity and flowering plants used in insectary plantings or maintained in field margins (Colley and Luna 2000, Harmon et al. 2000, Fiedler

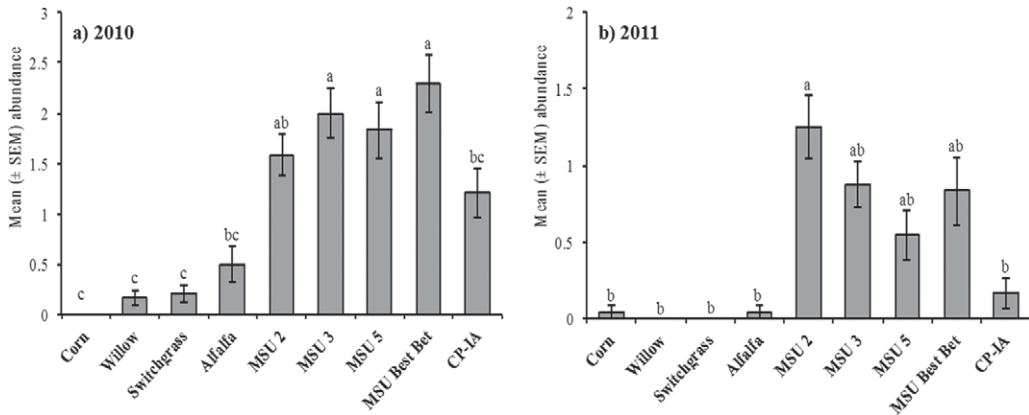


Fig. 2. Mean ± SEM abundance of bees across buffer treatments collected in (a) 2010 and (b) 2011 per plot. Means with common letters are not significantly different.

and Landis 2007b, Lundgren 2009, Lundgren et al. 2009, Al-Dobai et al. 2012).

Pollinator Abundance. We observed a pollinator community composed of 325 individual bees. During each year, we observed significant differences in the abundance of bees among buffer treatments. The mean number of bees per plot varied significantly across buffer treatments in 2010 ($F = 6.47$; $df = 8,215$; $P < 0.0001$) and 2011 ($F = 4.33$; $df = 8,215$; $P < 0.0001$). During 2010 we did not capture a single bee in corn; in 2011 we did not capture a single bee in either willow or switchgrass. Bees were more abundant in diverse and forb-only buffer treatments, from which we captured three to four times the mean number of individuals per plot than in simple buffer treatments (Fig. 2). Although these differences were not significant, noticeably more bees were found within forb-only and MSU Best Bet buffers compared with the CP-IA buffer (Fig. 2). Overall, the most bees (75) were collected from the MSU Best Bet buffer.

Lasioglossum spp. (Hymenoptera: Halictidae) were the most abundant bees collected in 2010. This group was present in all treatments except alfalfa. The great-

est number of *Lasioglossum* specimens (24) was observed in the MSU Best Bet and MSU3 buffers, accounting for 44% and 50% of the total bee abundance in these buffer treatments, respectively. In contrast, *Bombus griseocollis* (DeGeer) (Hymenoptera: Apidae) were the most abundant bees collected in 2011. *B. griseocollis* was only present in samples from the MSU Best Bet and forb-only buffers, with the greatest number of individuals (14) observed in the MSU2 buffer, accounting for 46% of the total bee abundance in that treatment.

Natural Enemy Abundance. We collected 7,520 natural enemies, of which predators accounted for a greater proportion than parasitoids (57% and 43%, respectively). Natural enemies were more abundant in diverse and forb-only buffer treatments containing multiple plant species and alfalfa, from which we collected 2–10 times the number of natural enemies per plot than the remaining simple buffer treatments (Fig. 3). The greatest number of natural enemies (1,602) was observed in the MSU Best Bet buffers. The mean number of natural enemies per plot varied significantly across buffer treatments in 2010 ($F = 9.15$; $df =$

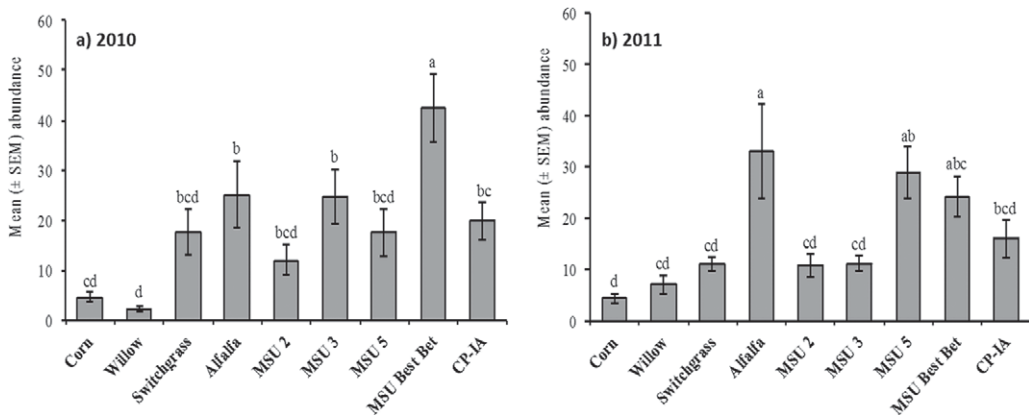


Fig. 3. Mean ± SEM abundance of natural enemies across buffer treatments collected in (a) 2010 and (b) 2011 per plot. Means with common letters are not significantly different.

Table 6. Summary of model selection statistics used for evaluating the influence of plant community characteristics on the species richness and abundance of bees and natural enemies vacuum collected in 2010 and 2011

Response variable ^a	K _i	AIC _c	ΔAIC _c	ω _i	Adj. R ²	Variables in model ^b
2010 Bee						
Richness	4	18.20	0.00	0.99	0.54	Plant diversity, flower no.
Abundance1	4	35.97	0.00	0.58	0.35	Flower no., plant diversity
Abundance2	5	36.65	0.68	0.41	0.29	Flower no.
2011 Bee						
Richness	3	-77.00	0.00	0.99	0.60	Flower no.
Abundance	3	-23.77	0.00	0.99	0.56	Flower no.
2010 Natural enemy						
Richness1	6	44.42	0.00	0.69	0.80	Plant diversity, flower no., ground cover, (canopy ht)
Richness2	5	46.09	1.67	0.30	0.78	Plant diversity, ground cover
Abundance	5	204.14	0.00	0.88	0.57	Plant diversity, flower no., ground cover
2011 Natural enemy						
Richness1	5	63.46	0.00	0.44	0.37	Plant diversity, flower no., ground cover
Richness2	4	63.83	0.37	0.36	0.33	Plant diversity, ground cover, (canopy ht)
Abundance1	5	183.20	0.00	0.56	0.41	Plant diversity, flower no., ground cover
Abundance2	4	184.21	1.01	0.34	0.36	Plant diversity, ground cover

For each best-fit and competing model we present the response variable, K_i = the no. of variables in each model, AIC_c = Akaike's Information Criterion adjusted for sample size, ΔAIC_c = difference in AIC_c score between best-fit and competing models, ω_i = Akaike weights as an estimate of the relative likelihood of a given model against all other models, and Adj. R² = R-square adjusted for the no. of terms in the model.

^a Where response variables are listed twice within guilds and years, the first model is the best-fit model based on the min. AIC_c and greater Adj. R² values. Competing models are listed second and only competing models with ΔAIC_c < 2 are shown.

^b Plant diversity is Simpson's 1/D, flower number is mean flower abundance per sampling event. Variables in parentheses indicate a negative relationship. (For details regarding plant characteristics see Methods and Materials: plant measurements; see Table 4 for plant characteristics comparisons across treatments).

8, 215; *P* = 0.0008) and 2011 (*F* = 8.79; *df* = 8, 215; *P* < 0.0001). In 2010, we observed significantly more natural enemies per plot within the MSU Best Bet buffers compared with all other buffers; in 2011 we did not observe significant differences among the MSU Best Bet, MSU5, and alfalfa buffers (Fig. 3).

In both years, *O. insidiosus* was the most abundant predator and was present in samples from all buffer treatments, but the most (523) were observed in the MSU Best Bet buffer, accounting for 36% of the total natural enemy community in this buffer treatment. Pteromalid wasps were the most abundant parasitoid family and were present in samples from all buffer treatments. The MSU5 buffer had the most pteromalids (384), comprising 34% of the total natural enemy community in this treatment.

Model Comparisons. Beneficial insect diversity and abundance exhibited positive relationships with several of the plant characteristics measured among buffer treatments. All best-fit and competing models were significant (*P* < 0.05). During 2010, we observed a significant positive relationship between bee species richness and plant diversity and the number of flowers in bloom (Table 6). In 2010, a competing model based solely on flower abundance was also significant. In 2011, the variables in the best-fit models for both bee species richness and abundance were reduced to a significant positive relationship with the number of flowers and no competing models. During both years we observed a significant positive relationship between species richness and abundance of natural enemies and plant diversity, the number of flowers in bloom, and ground cover in the best-fit models. In 2010, there was evidence for a competing model for natural enemy species richness and in 2011 there was evidence for a competing model for both natural en-

emy abundance and species richness. In addition to the positive relationships, we observed a significant negative relationship between natural enemy species richness and canopy height for the best-fit model in 2010 and competing model in 2011.

Discussion

We successfully established nine different plant communities with sufficient aboveground growth in both years to observe consistent trends in the diversity and abundance of beneficial insects. Diversity and abundance of bees and natural enemies was 1) greatest in buffers with diverse plant communities with continuous availability of floral resources, 2) intermediary in buffers reduced in species richness and availability of floral resources, and 3) lowest in buffers composed of a single species. Based on these observations, we propose that buffer strips could be optimized with native plants to attract multiple guilds and species of beneficial insects. Overall, our results suggest that 1) plant communities used in current buffer strips on organic farms (at least within Iowa) are not optimal for conserving beneficial insects, 2) the addition of flowering perennial species can improve buffer strips as habitats for beneficial insects, 3) combinations of native perennial plants can attract beneficial insects even at modest levels of plant diversity, and 4) plant communities recommended for prairie reconstruction may not contain the most attractive native species at densities necessary to attract multiple guilds of beneficial insects.

We hypothesized that diversity and abundance of beneficial insects would be limited in single-species plant communities (simple buffers) compared with moderately diverse (forb-only buffers) and mixtures

of forbs and grasses (diverse buffers). Our results agree with our predictions; however, we also observed significant variation in beneficial insect communities among the simple buffers. These results indicate that some simple buffers may be more suitable habitats than others. Among the simple buffers, bee and natural enemy communities were more diverse and abundant on perennial plants than the annual plantings of corn. Perennial buffer strips may be more hospitable refuges for beneficial insects than ephemeral plant communities. However, we did not observe a significant difference in beneficial insect abundance between corn and willow, an introduced perennial. The low abundance of insects on willow may be a product of our sampling methodology. Willow flowers in the spring, which may provide insects with food resources. However, we sampled later in the season when those resources were not present on willow and were more abundant on other plants. Our data suggest that for a buffer to be attractive to beneficial insects, it should consist of plants, which combined, provide season-long floral resources and vegetative ground cover, in addition to being perennial.

Switchgrass is a native perennial grass commonly used in conservation programs (USDA–NRCS 2011) and is being explored for bioenergy (Prochnow et al. 2009). The results of our study indicate that switchgrass monocultures were not effective for increasing beneficial insect abundance or diversity. In both years, natural enemy communities in switchgrass did not significantly differ from corn and willow. Bee communities did not significantly differ among any of the simple buffers, and bees were absent in switchgrass in 2011. In contrast to corn and willow, switchgrass shared some characteristics (e.g., a greater percentage of ground cover) that, as indicated by our analyses, have a positive relationship with the diversity and abundance of natural enemies. However, switchgrass, like corn, lacks components (e.g., floral resources) found in plant communities that had a more diverse and abundant beneficial insect communities, making it a sub-optimal candidate for buffer strips.

Gardiner et al. (2010) observed that the beneficial insect communities varied significantly across fields (>2 ha) of corn, switchgrass, and mixed prairie. Specifically, bee abundance and species richness of lady beetles was greater in switchgrass monocultures and mixed prairie polycultures compared with corn (Gardiner et al. 2010). We also observed the greatest insect abundance and diversity in plant communities composed of prairie plant species; however, beneficial insect communities did not differ significantly between corn and switchgrass. As noted by Gardiner et al. (2010), the switchgrass fields that they used were planted as part of the Conservation Reserve Program and contained a mean of 27 plant species. Gardiner et al. (2010) suggested that if switchgrass is planted as a dedicated biofuel crop, it would be managed to promote single-species stands, which would likely have few beneficial insects. The community of beneficial insects we observed in our switchgrass plots was likely the product of management that produced a monocul-

ture of switchgrass. We suggest that the value of switchgrass as a buffer for organic farms will depend on how it is established and managed.

In contrast to the other simple buffer treatments, alfalfa had several characteristics (e.g., percent ground cover, floral resources) that, as indicated by our analyses, have a positive relationship with the diversity and abundance of beneficial insect communities. Natural enemy communities were significantly more diverse and abundant in alfalfa compared with corn and willow in both years, and additionally to switchgrass in 2011. However, the same was true for herbivores in alfalfa in both years of our study. Alfalfa can provide multiple resources for beneficial insects; however, the management used in Iowa to manage pests (e.g., *E. fabae*) below economic thresholds includes insecticide applications and early alfalfa harvest (Lefko et al. 1999). Insecticides are not compatible with organic production, and early harvest can remove habitat and prey, and therefore, natural enemies. We did not manage our plots in this manner and uncut alfalfa plots became infested with *E. fabae* in both years.

Unmanaged pest populations in our alfalfa plots may be partially responsible for recruiting larger populations of natural enemies. Therefore, our results may overestimate the ability of alfalfa to attract natural enemies. In addition, bee diversity and abundance in alfalfa was not significantly different from corn in 2010 and willow and switchgrass in 2011, where bees were not observed. Despite these results, alfalfa can be an attractive option for a buffer when it doubles as a harvestable forage crop. This may apply to a subset of organic farmers involved in livestock production. In this situation, benefits may increase when alfalfa is harvested in strips (Weiser et al. 2003), such that not all habitat for beneficial insects is removed at once.

Among the nine treatments, in both years, the MSU Best Bet buffer was consistently one of the most attractive for both bees and natural enemies. Regarding bees, halictids were particularly diverse and abundant in the MSU Best Bet buffer. Several species of halictids are responsible for pollinating crops including field-grown tomato (Greenleaf and Kremen 2006), watermelon (Kremen et al. 2004), and canola (Morandin and Winston 2005). Therefore, an abundance of halictids may lead to pollination of crops across multiple bloom periods. In 2011, the most abundant bee species in MSU Best Bet and forb-only buffers was the bumblebee, *B. griseocollis*. *Bombus* species are also known to pollinate the crops listed above, and are especially effective pollinators of crops that require sonication or buzz pollination. Halictid and *Bombus* spp. were consistently observed in the MSU Best Bet even when populations of these insects fluctuated between years among the other buffer treatments. Several species of parasitoids (braconids and pteromalids), and the predatory, *O. insidiosus*, were also abundant in the MSU Best Bet buffer. Like pollinators, natural enemies have a well-established role in agroecosystems. These natural enemies can attack a wide range of herbivorous insect pests. To summarize, the MSU Best Bet

buffer supported a diverse and abundant beneficial insect community that can provide a suite of ecosystem services that complement organic and conventional cropping systems.

Despite having the same species richness of grasses and forbs, we observed differences in the beneficial insect community between the CP-IA and MSU Best Bet buffers. Typically, reconstructed prairies have a greater proportion of grass compared with forbs; however, we manipulated these ratios to contain a greater proportion of forbs in both the MSU Best Bet (76% forbs and 24% grass) and CP-IA (68% forbs and 32% grass). This forb-rich ratio was used to optimize the plant communities, so each of these diverse treatments provided floral resources to accommodate a range of insect species. The forbs in the MSU Best Bet buffer produced a greater number of flowers than the CP-IA, contributing to a difference (that was not always significant) in the diversity and abundance of bees and natural enemies. Differences among these forb-rich mixtures reinforce the importance of the decision-making process in targeted conservation efforts. To conserve beneficial insects with buffers by carefully reintroducing native flowering plants will require considering their density at the farm and landscape scale. For example, in a landscape-scale study conducted in the same eco-region as our research site, attractive forb species similar to those in the MSU Best Bet buffer treatment were present in a large (>1,619 ha) reconstructed prairie embedded in cropland composed of a corn-soybean rotation (Schmidt et al. 2011). Despite the proximity of prairies to cultivated fields, no increase in natural enemy abundance or diversity was observed in adjacent crops. Schmidt et al. (2011) suggested that densities of these plant species in traditional prairie restorations may not be optimal for enhancing both biological diversity and functional diversity at the landscape scale. At smaller scales, differences in plant diversity may result in an observable effect on the insect community, as noted by Rebeck et al. (2005).

The importance of conserving beneficial insects to maintain ecological processes is being increasingly recognized, and previous work has focused on the relationship between successful crop production and insect-derived services, like biological control. In a review of studies that investigate how habitat management can promote conservation biological control, Fiedler et al. (2008) found that most studies described the relationship of natural enemies to specific plants. Among the 34 studies reviewed, the majority of the 165 plant species documented were exotic. Gaps in research regarding the advantages of using native plants over exotic plants for enhancing ecosystem services mediated by beneficial insects are increasingly being addressed (Fiedler and Landis 2007a, Frank et al. 2008, Tuell et al. 2008). These studies, along with the results presented here, suggest that buffer strips have the potential to provide benefits beyond simply meeting requirements for organic certification. Realizing these benefits will require outreach to farmers and policy writers and representatives of conservation agencies

who consider incentives that promote management practices to acquire multiple ecosystem services from buffer strips.

In summary, the results from our field experiment indicate plant communities that dominate existing buffer strips and lands designated for conservation may not be optimal for beneficial insects. Adding flowering perennial species can improve buffer strips as habitats for beneficial insects, especially bee pollinators. Moreover, buffer strips can be further optimized by intentionally combining the most attractive native species even at modest levels of plant diversity, such that flowering resources are available throughout the growing season. In conclusion, conservation of beneficial insects appears to be a product of a high density of the attractive native species (i.e., quality), and not necessarily a product of a habitat made up of many native plant species (i.e., quantity).

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