RESEARCH ARTICLE

Diversifying Agricultural Catchments by Incorporating Tallgrass Prairie Buffer Strips

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ABSTRACT

Crop production and prevailing farming practices have greatly reduced biodiversity and nearly eliminated native prairie in the central USA. Restoring small areas of prairie on cropland may increase plant biodiversity and native species abundance while benefiting the cropland. In Iowa, we incorporated buffer strips composed of prairie vegetation within catchments (0.5 ha to 3.2 ha land areas in which precipitation drained to a collection point at the slope bottom) used for corn (*Zea mays*) and soybean (*Glycine max*) production. We planted prairie buffer strips in three designs, varying the proportion of the catchment converted to buffer and/or the continuity of the buffer. Within the catchments, we determined the identity and percent cover of buffer strip plant species during 2008–2011 and of weed species in cropped areas during 2009–2011. We found 380% more species in 6 m² of buffer strip than in 6 m² of crop, indicating that the presence of buffer strips greatly increased catchment diversity. Plant community composition did not differ among the three buffer designs. Despite being surrounded by cropland, the buffer vegetation was dominated by native perennial species—the targeted vegetation type for both ecohydrological functions (e.g., erosion control) and native species conservation—within four years of establishment. Furthermore, weed species richness and prevalence did not differ between cropped areas of catchments with buffer strips and cropped areas of catchments without buffer strips. These results indicate that converting 10–20% of cropland to prairie buffer strips successfully reintroduced perennial species characteristic of native prairie without increasing weeds in adjacent crops.

Keywords: plant diversity, prairie strips, STRIPs, tallgrass prairie restoration, weeds

Agriculture is the leading cause of land-use change, with croplands and pastures covering 12 and 26%, respectively, of the Earth's ice-free land area (Foley et al. 2011). Currently, humans farm more land area at higher resource intensity than ever before and divert an increasing amount of products to non-food uses (e.g., biofuels) (Foley et al. 2011). The loss of temperate grasslands, savannas and shrublands is of particular concern, as they have the highest ratio of agriculturally-converted habitat (45.8%) to protected area (4.6%), and are the least protected of the world's 13 biomes (Hoekstra et al. 2005). In particular, the Midwestern USA is classified as a 'critically endangered' ecoregion because greater than 50% of the region's native vegetation has been converted to other vegetation types and the ratio of converted to protected land is >25:1 (Hoekstra et al. 2005). In Iowa, from Euro-American settlement to the 1990s, prairie decreased from covering approximately 85% (>12 million hectares) to only 0.01% of the state (Eilers and Roosa 1994, Samson and Knopf 1994).

This land-use change is the leading driver of biodiversity loss within grasslands (Sala et al. 2000). In Iowa, 74% of the total land area has been converted to cropland, and 86% of the cropland is planted in corn (*Zea mays*) or soybean (*Glycine max*) (USDA 2009). Currently, farmers typically practice a corn-soybean rotation, which replaced more complex, diverse crop rotations practiced prior to World War II that included perennial plants in hay fields and pastures (Bultena et al. 1996, Brummer 1998). Moreover, plant diversity has been largely eliminated on field margins. In the 1940s, due to the advent of larger farm equipment and pressure during World War II to cultivate as much land as possible, farmers began shifting from small farms surrounded with brushy, perennial fencerows to larger expanses of uninterrupted cropland (Bultena et al. 1996).

Widespread loss of biodiversity associated with agricultural land-use change is not only alarming from the perspective of nature conservation, but also can negatively impact humans and their economies (Hoekstra et al. 2005). While current land-use practices increase short-term supplies of food, fiber, and fuel, they may undermine ecosystem services essential for productive agriculture and be harmful to human welfare (Foley et al. 2005). For example, reducing vegetation richness can negatively influence soil formation, erosion control, water retention, and nutrient cycling (Schulte et

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al. 2006). Additionally, native, diverse vegetation may encourage crop pollination and promote natural enemies of insect pests (SAN 2003).

Incorporating buffer strips (intentional areas of non-crop vegetation within agricultural catchments) composed of diverse plant species may be an especially useful conservation practice for crop-dominated landscapes (Lovell and Sullivan 2006). In previous investigations conducted in Pennsylvania, conserving or expanding non-crop area within crop-dominated landscapes had a much larger impact on conserving plant richness than did altering agricultural management practices (e.g., increasing crop diversity or reducing herbicide use to allow more species to coexist within the crops) to encourage more species (Egan and Mortensen 2012).

In this study, our aim was to reintroduce tallgrass prairie vegetation, a diverse plant community native to central Iowa and dominated by perennial species, to the Iowa landscape in the form of buffer strips. The STRIPs (Science-based Trials of Row crops Integrated with Prairies) project, initiated in 2007, investigated how prairie buffer strips (also called multipurpose prairie strips) placed within catchments (land areas in which precipitation drained to a collection point at the slope bottom) used for corn and soybean production affect ecohydrology, biodiversity, and socioeconomic dynamics. In the present study, we specifically investigated how the vegetation in the prairie buffers developed during the first four years after planting and whether the prairie vegetation would spread into the cropped areas of the catchments.

We focused on three questions. First, would the prairie buffers develop as intended, following succession patterns typical to prairie establishment and shifting from annual, weedy vegetation to perennial prairie grasses and forbs within three to four years, despite being adjacent to conventionally managed crops? The cropland, treated with fertilizers and herbicides, might hinder the succession of the buffer strips through nutrient runoff or herbicide drift. For example, Rothrock and Squiers (2003) found that N fertilized prairie communities remained dominated by annual weeds and did not shift to perennial species. Alternatively, Jarchow and Liebman (2012) found that spring fertilization of prairies increased late season prairie species diversity and did not encourage exotic species.

Second, would the proportion of the agricultural catchment converted to prairie buffer or the continuity of the buffer affect plant community composition? Specifically, would plant community composition differ if 10 versus 20% of the catchment were prairie buffer or if the prairie buffer were continuous versus broken into multiple strips? More extensive or numerous strips might encounter heterogeneous environments that favor different species, and buffer strips with large edge-to-area ratios might provide habitat for undesirable species that grow on borders between vegetation types (Diamond and May 1981, Kunin 1997, With 2004).

Finally, we asked if prairie buffer strips would increase weeds in the cropped areas of the catchments. Some farmers express concern that unsprayed non-crop vegetation bordering crops could encourage weeds in adjacent crops (van der Meulen et al. 1996, Marshall 2009). Farmers might have similar concerns that plants from buffer strips would spread into the crop of the catchments and reduce crop yields.

Methods

We conducted our work within the Neal Smith National Wildlife Refuge, in central Iowa, USA (41°32' N, 93°15' W) in 12 0.5 ha to 3.2 ha catchments (mean = 1.3 ha) containing row crops. The catchments had 6.1–10.5% slopes. We planted prairie grasses and forbs native to Iowa (Table 1) as buffer strips in portions of nine of the 12 catchments; the remaining three catchments were 100% crop (Figure 1). We planted the buffer strips in three designs (treatments): (1) one buffer strip at the bottom of the catchment slope, comprising 10% of the area ('10% bottom'); (2) two or three buffer strips distributed at the bottom of the catchment slope and upslope, comprising 10% total of the area ('10% strips'); (3) two or three buffer strips distributed at the bottom of the catchment slope and upslope, comprising 20% total of the area ('20% strips'). The control treatment was 100% row crop with no buffer strips ('100% crop') (Figure 1). There were three replicate catchments for each of the four treatments; the 12 catchments were arranged in four blocks using a balanced incomplete-block design.

Catchments in two of the blocks were planted in prairie in 2005, but heavily dominated by the non-native perennial grass smooth brome (*Bromus inermis*) before the start of the experiment, and catchments in the remaining two blocks were heavily dominated by smooth brome for at least 10 years prior to the experiment. The 12 catchments were tilled in August 2006 and May 2007 to disrupt the sod and level the ground. Starting in 2007, a local farmer managed the catchments in an alternate year corn-soybean rotation using no-till techniques, synthetic fertilizers and glyphosate herbicide. We broadcast seeded the buffer strips on 6 July 2007 with a single tallgrass prairie seed mix, which was collected on the refuge in the fall of 2006 using a combine equipped with a 6-meter-wide rice head. The timing of the seeding was based on the availability of equipment and labor, and the refuge's prior success with mid-summer seedings. Species composition of the seed mixture was determined visually by analysts at the Iowa State University Seed Testing Laboratory and 31 species were identified (Table 1). One additional species, *Anemone canadensis*, was obtained from a local seed supplier and added to the mixture. We mowed the buffer strips in June and

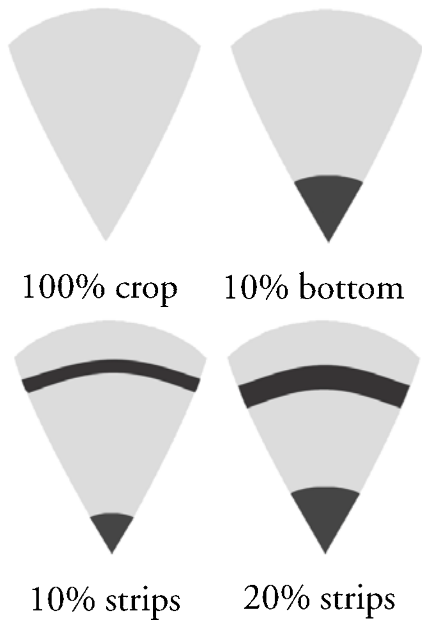

Figure 1. Schematic representation of the catchment design treatments. 10% bottom = 90% of the catchment as crop and 10% as one buffer strip at the bottom of the catchment slope; 10% strips = 90% of the catchment as crop and 10% as two to three buffer strips at the bottom of the catchment slope and upslope; 20% strips = 80% of the catchment as crop and 20% as two to three buffer strips at the bottom of the catchment slope and upslope; 100% crop = 100% of the catchment as crop.

Table 1. Species present in prairie seed mix collected at the Neal Smith National Wildlife Refuge and the proportion of catchments in which we identified these species at least once in vegetation surveys during 2008–2011. Percentages of seed mix components by weight were 27% grasses (G), 24% forbs (F), 5% weedy forbs (WF) and weedy grasses (WG), and 44% inert matter. Buffer strips were sown on 6 July 2007, with the exception of *Anemone canadensis*, which was sown on 22 April 2008.

Species	Group	Proportion of sites established
Andropogon gerardii	G	9/9
Bouteloua curtipendula	G	9/9
Elymus canadensis	G	9/9
Elymus virginicus	G	1/9
Schizachyrium scoparium	G	9/9
Sorghastrum nutans	G	9/9
Sporobolus spp.	G	3/9
Amorpha spp.	F	0/9
Anemone canadensis	F	5/9
Asclepias spp.	F	7/9
Aster spp.	F	9/9
Chamaecrista fasciculata	F	9/9
Coreopsis spp.	F	0/9
Heliopsis helianthoides	F	9/9
Lespedeza capitata	F	8/9
Liatris spp.	F	0/9
Monarda fistulosa	F	9/9
Ratibida spp.	F	9/9
Solidago rigida	F	1/9
Ambrosia artemisiifolia	WF	9/9
Ambrosia trifida	WF	5/9
Bidens polylepis	WF	0/9
Brickellia eupatorioides	WF	6/9
Chenopodium album	WF	7/9
Daucus carota	WF	9/9
Lactuca serriola	WF	4/9
Trifolium repens	WF	9/9
Polygonum convolvulus	WF	0/9
Polygonum pensylvanicum	WF	9/9
Rumex crispus	WF	9/9
Setaria faberi	WG	9/9
Muhlenbergia spp.	WG	6/9

August 2008 and June 2009, without removing the cuttings, and in October 2010 and November 2011, removing the cuttings. The mowing schedule was intended to enhance desirable species and suppress weeds in the buffers and was considered a realistic scenario for land managers. We spot treated Canada thistle (*Cirsium arvense*), a highly invasive non-native plant species, in the prairie buffer strips with aminopyralid in 2009 and glyphosate in 2010 and 2011.

Annually from 2008–2011, we surveyed twelve 0.5 m² quadrats (50 × 100 cm) in the buffer vegetation of each of the nine catchments containing restored prairie buffer strips. We conducted our surveys during July-August to capture the peak flowering period. We placed quadrats equidistant along a straight transect, placing the first and last quadrats 2 m from the crop edge (mean distance between quadrats ± SE was 23 ± 3 m). In catchments with one, two, or three buffer strips, we surveyed twelve, six, or four quadrats, respectively, along a single transect in each buffer strip. We used the same number of quadrats per catchment regardless of size in order to be able to determine species diversity for a constant area. In addition, annually from 2009–2011, to evaluate if buffer strip plants were present within the cropped areas of the catchments, we surveyed twelve 0.5 m² quadrats within the crop of each of the nine catchments containing prairie buffer strips as well as in each of the three 100% crop catchments. Quadrats were placed equidistant along a straight transect in each segment of cropped areas. The cropped areas were treated with glyphosate in May and June 2009, May 2010, and May and July 2011.

In preliminary analyses, we assessed whether vegetation surveys adequately assessed the plant community composition. In 2010 and 2011, we surveyed twenty-four 0.5 m² quadrats (rather than the typical twelve) in the prairie buffer strip of the three catchments in the 10% bottom treatment. Species accumulation curves and rank abundance curves of 12 versus 24 quadrats indicated that surveying 12 quadrats in the buffer strip was adequate to accurately assess the dominant species and proportions of species in various life-history groups (Hirsh 2012). Following classic species-area predictions, however, several more sparse species were present in the buffer strips assessed with 24 quadrats than the 12 quadrat surveys indicated (Hirsh 2012).

During the vegetation surveys, we determined the number (species richness), identity, and percent cover (percentage of the quadrat covered by a species when vertically projected onto the ground) of each plant species within the quadrats. We estimated percent cover in seven classes: 0–1%; >1–5%; >5–25%; >25–50%; >50–75%; >75–95%; or >95–100%; using the midpoints of each class for analyses (Bonham 1989). Each species was observed independently for percent cover to adequately survey plants of varying heights; therefore, quadrats with multiple vegetation layers could contain >100% cover. We identified plants to the species level when possible, and characterized them into 10 life-history groups: native perennial grass, native annual grass, non-native perennial grass, non-native annual grass, native perennial forb, native biennial forb, native annual forb, non-native perennial forb, non-native biennial forb, and non-native annual forb (Eilers and Roosa 1994, NRCS 2012). Grasses, sedges and rushes were all treated as one group: graminoids.

We summarized the plant species composition within the buffer strips of the nine catchments and the weed species composition within the cropped areas of the 12 catchments among years using non-metric multidimensional scaling (NMS) ordination (Kruskal 1964, Mather 1976) to understand temporal patterns in community composition. In our study, weed species were considered to be all non-crop plant species within the cropped areas of the catchments. We understand "weed" is subjective and that the meaning of the term can differ depending on user; however, it is commonly used in agriculture to designate non-crop species within crops. NMS is a multivariate statistical technique that creates continuous composite variables (axes or dimensions) from the original variables (species), and is appropriate for ecological community and non-normally distributed data (McCune and Grace 2002). NMS arranges sites along output axes according to their similarity or dissimilarity. In our case, NMS arranged catchments along axes according to their species composition, with similar catchments plotted closer together and dissimilar catchments plotted farther apart. We measured distances with Sorensen/Bray-Curtis distance in the original, unreduced space and with Euclidean distance in the ordinated, reduced space. NMS iteratively searched for the best positions of the sites (catchments) along the axes to minimize the amount of 'stress' in the final solution; stress measured how different the ordination dimension arrangement was from the original dimension arrangement (McCune and Grace 2002). Stress values of 10–15 are considered satisfactory for ecological community data (McCune and Grace 2002). A coefficient of determination (R^2) between the original space and ordination space distances was used to evaluate the quality of data reduction, with $R^2 \times 100$ indicating the percentage of variance represented by each axis. Generally, data sets with > 20 species should explain > 50% of the variation with two axes (McCune and Grace 2002). We conducted NMS analyses using PC-ORD software version 6.04 (MjM Software, Gleneden Beach, OR, USA). For analysis of the plant species composition within the buffer strips of the nine catchments, we ran the autopilot 'slow and thorough' mode, which used random starting configurations, compared 250 runs with the real data to 250 runs with randomized data (Monte Carlo tests), chose the lowest dimensionality in which stress would not be reduced by five had the dimension been one higher, and attempted to find a solution until instability was 0.0000001 or 500 runs were performed. For analysis of the weed species composition within the crop of the 12 catchments, we found the NMS solution for two dimensions using Sorensen/Bray-Curtis distance measure (random starting configuration, Monte Carlo tests).

The joint plots produced by NMS analysis illustrate how catchment positions in ordination space relate to their species. Points represent a particular catchment (site) and are positioned according to their species composition. The angle and length of vector lines (representing species) radiating from the ordination space center show the direction and the strength of the relationship between vectors and catchments. Vectors represent species with greater than a set R^2 value, representing in this case the proportion of variation in position on the ordination axis explained by the species.

We calculated buffer strip species richness and Simpson's diversity index ($1/D$) for the twelve 0.5 m^2 quadrats (6 m^2 total area) in each catchment. Simpson's diversity index, a measure of diversity based on species evenness and richness, represents the number of species if all species were equally abundant ($D = \sum_i^S p_i^2$; p_i = proportion of individuals belonging to species i; S = number of species). We calculated the percent cover and relative percent cover (mean of 12 quadrats) of each life-history group for the buffer strip vegetation. In the cropped areas of catchments with buffer strips and of 100% crop catchments, we calculated weed (non-crop) species richness for the twelve 0.5 m^2 quadrats (6 m^2) and total percent cover (mean of 12 quadrats). We analyzed effects of treatment, year, and the interaction of treatment and year on the buffer strip dependent variables of total, perennial, native, and native perennial species richness and percent cover, and perennial, native, and native perennial relative percent cover (arcsine-square root transformed). We

Table 2. Vegetation of the tallgrass prairie buffer strip(s) in catchments from 2008–2011. Results of analysis of variance (*F* statistics, *p* values) are presented for the effect of year on the dependent variables of total, perennial, native, and native perennial (NP) species richness and percent plant cover; perennial, native, and native perennial relative percent plant cover; and Simpson's diversity. Mean values for the catchments and their standard errors (SE) for surveys conducted in 2008–2011 are also presented. Numerator degrees of freedom = 3; denominator degrees of freedom = 18; different lowercase letters within rows indicate significant differences among years ($p < 0.05$, Tukey-Kramer adjusted). Relative percent cover values are arcsine-square root transformed; untransformed values are in parentheses.

	F	*p*	2008 LSM	2009 LSM	2010 LSM	2011 LSM
Species richness						
All species	14.8	<0.0001	37.8 ± 1.1^{a}	45.3 ± 2.2^{b}	51.4 ± 1.6^{c}	55.1 ± 2.2^{c}
Perennial species	32.6	<0.0001	25.2 ± 0.7^{a}	33.9 ± 1.5^{b}	40.3 ± 1.4^{c}	45.0 ± 2.1^{d}
Native species	12.0	0.0001	25.3 ± 1.0^{a}	30.6 ± 1.6^{b}	35.2 ± 1.4^{c}	38.7 ± 2.2^{c}
NP species	24.3	<0.0001	18.0 ± 0.7^{a}	24.4 ± 1.2^{b}	29.0 ± 1.1^{c}	33.2 ± 2.1^{d}
Simpson's diversity	7.7	0.0016	5.7 ± 0.8^{a}	8.3 ± 0.9^{ab}	11.5 ± 1.3^{c}	10.3 ± 1.3^{bc}
Percent cover						
All species	17.0	<0.0001	82.2 ± 4.5^{a}	74.9 ± 3.4^{a}	105.0 ± 5.9^{b}	115.1 ± 3.9^{b}
Perennial species	36.9	<0.0001	30.5 ± 3.8^{a}	58.6 ± 5.1^{b}	94.0 ± 6.2^{c}	103.9 ± 4.3^{c}
Native species	25.8	<0.0001	38.2 ± 3.1^{a}	24.3 ± 2.0^{b}	57.1 ± 5.2^{c}	68.7 ± 3.4^{c}
NP species	51.6	<0.0001	17.7 ± 1.4^{a}	21.5 ± 1.9^{a}	55.2 ± 4.9^{b}	66.4 ± 3.2^{b}
Relative percent cover						
Perennial species	39.6	<0.0001	0.65 ± 0.04^{a} (37.1±3.7)	1.09 ± 0.05^{b} (78.3±4.1)	1.25±0.03^{bc} (89.5±2.0)	1.27±0.03^{c} (90.3±2.0)
Native species	15.9	<0.0001	0.77±0.05^{a} (46.5±5.4)	0.61±0.03^{b} (32.5±2.6)	0.83±0.03^{a} (54.4±3.4)	0.89±0.03^{a} (59.7±2.9)
NP species	55.6	<0.0001	0.48±0.02^{a} (21.5±1.7)	0.56±0.03^{b} (28.7±2.4)	0.81±0.03^{c} (52.6±3.2)	0.87±0.03^{c} (57.7±2.7)

arcsine-square root transformed relative percent cover values because the values were not between 30–70, and were therefore constrained by upper and lower limits, and the variance of the values was dependent on the mean (Gomez and Gomez 1984, Gotelli and Ellison 2004). In addition, we analyzed effects of treatment, year, and the interaction of treatment and year on the crop dependent variables of weed species richness and weed percent cover. We ran all tests using repeated-measures analysis of variance (ANOVA), computed with the PROC MIXED method in SAS v. 9.2 (SAS Institute Inc., Cary, NC, USA). The age of succession (year effect) was the repeated factor; blocks were a fixed effect. Tukey post-hoc pairwise comparisons were used to determine differences among years for catchment least squares means.

Results

Within the 54 m^2 area surveyed in the buffer strips across all nine catchments that incorporated buffer strips, we found a total of 82 different species in 2008, 103 species in 2009, 122 species in 2010, and 118 species in 2011. Within the 6 m^2 area surveyed in the buffer strip(s) of a single catchment, on average we found 37.8 species providing 82.2% cover in 2008, 45.3 species providing 74.9% cover in 2009, 51.4 species providing 105.0% cover in 2010, and 55.1 species providing 115.1% cover in 2011 (Table 2). In 2008–2011, 90% of the total percent plant cover was made up of 26–30 species, depending on the year (the 15 most dominant are listed in Table 3).

We found no differences among buffer strip designs (varying the proportion of the agricultural catchment converted to prairie buffer and/or the continuity of the buffer) for mean species richness of total, perennial, native, and native perennial species (minimum $p = 0.3696$); mean Simpson's diversity ($p = 0.1937$); mean total, perennial, native, and native perennial percent cover (minimum $p = 0.3050$); and arcsine-square root transformed value of the mean relative perennial, native, and native perennial percent cover (minimum $p = 0.3938$) in the buffer strip(s)/catchment. Furthermore, we found no interaction between buffer strip designs and the year (i.e., stage of succession) for any of the dependent variables (minimum $p = 0.3989$), indicating there were no differences between buffer treatments during any stage of succession. However, as expected, over time, we recorded increases in mean species richness of total, perennial, native, and native perennial species; mean Simpson's diversity; mean total, perennial, native, and native perennial percent cover; and arcsine-square root transformed values of the mean relative perennial percent cover and native perennial percent cover in the buffer strip(s)/catchment (Table 2 and Figure 2).

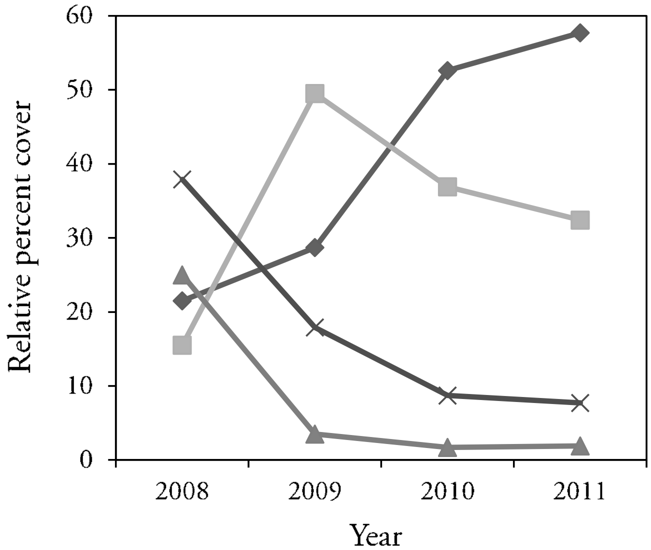

Figure 2. Relative percent cover of tallgrass prairie buffer strip species in various life-history groups in 2008, 2009, 2010, and 2011. Diamonds represent native perennial species, squares represent non-native perennial species, triangles represent native annual/biennial species, and exes represent non-native annual/biennial species.

The NMS joint plot depicting plant species composition within the buffer strips of the nine catchments clearly depicts a temporal shift in dominance of non-desirable annual species to perennial species within the buffer strips. For example, vectors representing the annual grasses foxtail (*Setaria* spp.) and witchgrass (*Panicum capillare*) point toward 2008 catchment composition, while vectors representing perennial bluegrass species (*Poa compressa / P. pratensis*), indiangrass (*Sorghastrum nutans*), and Canada goldenrod (*Solidago canadensis*) point toward 2010 and 2011 composition (Figure 3A). NMS analysis of 175 buffer strip species had an optimal dimensionality of two with a final stress of 12.0 using 41 iterations. Monte Carlo test results indicated a

Table 3. Dominant species in the tallgrass prairie buffer strips from 2008–2011. Mean percent cover values and standard errors (SE) of most prevalent 15 species found in each year.

2008		2009		2010		2011	
Species	Mean % cover (± SE)	Species	Mean % cover (± SE)	Species	Mean % cover (± SE)	Species	Mean % cover (± SE)
Setaria spp.	26.92 ± 4.35	*Trifolium hybridum*	12.31 ± 3.73	*Poa compressa/ P. pratensis*	21.81 ± 5.27	*Poa compressa/ P. pratensis*	25.65 ± 6.30
Panicum capillare	13.27 ± 4.68	*Poa compressa/ P. pratensis*	11.46 ± 3.93	*Solidago canadensis*	8.27 ± 1.59	*Solidago canadensis*	11.49 ± 2.44
Rumex crispus	4.06 ± 1.43	*Setaria* spp.	10.50 ± 2.09	*Ratibida pinnata*	6.59 ± 0.83	*Ratibida pinnata*	6.63 ± 1.48
Ratibida pinnata	3.43 ± 1.02	*Taraxacum officinale*	3.34 ± 1.04	*Daucus carota*	5.71 ± 1.34	*Daucus carota*	6.33 ± 1.46
Poa compressa/ P. pratensis	3.13 ± 1.56	*Rumex crispus*	2.74 ± 0.73	*Symphyotrichum pilosum*	5.45 ± 1.10	*Sorghastrum nutans*	5.57 ± 1.32
Daucus carota	2.28 ± 0.33	*Cyperus esculentus*	2.58 ± 0.57	*Sorghastrum nutans*	4.43 ± 1.00	*Monarda fistulosa*	4.33 ± 2.18
Medicago sativa	2.03 ± 0.96	*Ratibida pinnata*	2.46 ± 0.39	*Andropogon gerardii*	3.73 ± 1.40	*Andropogon gerardii*	4.30 ± 0.94
Bouteloua curtipendula	1.60 ± 0.48	*Daucus carota*	2.15 ± 0.30	*Elymus canadensis*	3.52 ± 0.99	*Bromus inermis*	3.89 ± 0.91
Polygonum pensylvanicum	1.60 ± 0.66	*Trifolium repens*	1.86 ± 1.20	*Taraxacum officinale*	3.17 ± 0.57	*Symphyotrichum pilosum*	3.59 ± 0.61
Cyperus esculentus	1.47 ± 0.55	*Bouteloua curtipendula*	1.74 ± 0.58	*Setaria* spp.	2.95 ± 0.79	*Phalaris arundinacea*	3.09 ± 1.24
Chamaecrista fasciculata	1.29 ± 0.44	*Cirsium arvense*	1.65 ± 0.75	*Bromus inermis*	2.89 ± 0.81	*Heliopsis helianthoides*	3.07 ± 0.83
Potentilla norvegica	1.19 ± 0.40	*Elymus canadensis*	1.44 ± 0.31	*Lotus corniculatus*	2.77 ± 1.30	*Cyperus esculentus*	2.71 ± 0.86
Calystegia sepium	1.15 ± 0.82	*Solidago canadensis*	1.37 ± 0.27	*Bouteloua curtipendula*	2.65 ± 0.97	*Setaria* spp.	2.19 ± 0.70
Conyza canadensis	1.08 ± 0.45	*Bromus inermis*	1.22 ± 0.60	*Monarda fistulosa*	2.60 ± 0.86	*Schizachyrium scoparium*	2.16 ± 0.70
Rudbeckia hirta	1.07 ± 0.31	*Calystegia sepium*	1.18 ± 0.72	*Trifolium repens*	2.34 ± 1.17	*Elymus canadensis*	2.11 ± 0.37

0.004 probability of obtaining a similar final stress by chance. The percentages of variance represented by axes one and two were 72% and 15%, respectively.

Catchments containing prairie buffer strips did not have more weeds or different weeds than catchments without buffer strips. Non-crop plant species richness and percent cover were low in all 12 catchments. There were no differences among catchments for mean weed species richness ($F = 1.42$; $p = 0.3417$) or percent cover ($F = 0.69$; $p = 0.5984$), regardless of whether the catchment contained buffer area or was 100% crop (Figure 4). There was no interaction between catchment design and year (stage of succession) for species richness ($F = 1.55$; $p = 0.2263$) or percent cover ($F = 0.98$; $p = 0.4693$). Moreover, the NMS joint plot depicting the weed species composition within the cropped areas of the 12 catchments indicated that the species composition of the crop did not resemble the species composition of the buffer strips (Figure 3). The NMS analysis of 89 weed species had two dimensions, a stress of 13.6, and used 63 iterations. Monte Carlo test results indicated a 0.004 probability of obtaining a similar final stress by chance. The percentages of variance represented by axes one and two were 57% and 30%, respectively.

Non-crop species in the cropped areas of the catchments were similar from year to year (Table 4). Mean species richness and percent cover of non-crop species were low overall, although they increased from 2009–2010 (Table 5). However, the non-crop species in the cropped areas included few native species, showing no evidence that prairie plants were moving into the crops.

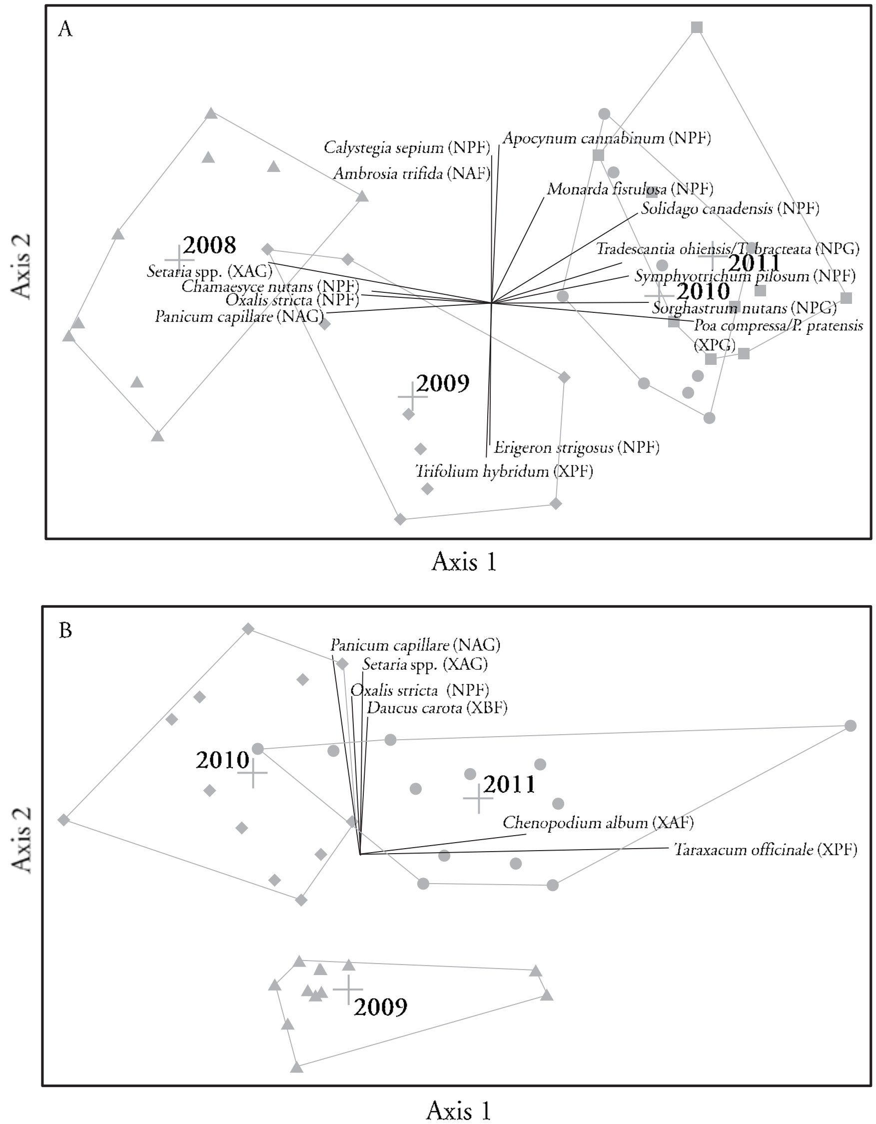

Figure 3. Non-metric multidimensional scaling (NMS) joint plots: A) species composition within buffer strips in nine catchments during 2008–2011, and B) weed species composition within cropped areas in 12 catchments during 2009–2011. Distance between catchments in the ordination space approximates the amount of dissimilarity between catchments in terms of their species composition. Catchments in each year enclosed by convex hulls; dominant species depicted with vectors; A) $r^2 = 0.3$ vector cut-off, and B) $r^2 = 0.35$ vector cut-off. NPG = native perennial grass, NAG = native annual grass, XPG = non-native perennial grass, XAG = non-native annual grass, NPF = native perennial forb, NBF = native biennial forb, NAF = native annual forb, XPF = non-native perennial forb, XBF = non-native biennial forb, XAF = non-native annual forb.

Discussion

Our work indicates that the presence of buffer strips composed of prairie species within small catchments used for corn and soybean production can greatly increase plant diversity without increasing weeds in the cropped areas of catchments. Averaged over the period of 2009–2011, 6 m² of crop contained 13 species, whereas 6 m² of prairie buffer strip contained 51 total species. Moreover, within three years of planting, prairie buffer strip vegetation had 5.8 times more native species than crop vegetation (35 versus 6 native species). The plant community composition did not differ as a result of the proportion of the agricultural catchment converted to prairie buffer strip or the continuity of the buffer—the three buffer designs we considered performed equally well in terms of increasing the richness and cover of native prairie species in the study catchments. This suggests different prairie buffer designs are robust in meeting biodiversity goals, offering farmers flexibility in situating buffers based on landscape or crop management constraints.

Table 4. The ten most prevalent weed species in crop fields associated with tallgrass prairie buffer strips in 2009, 2010, and 2011. The life-history group (LHG) of the species, mean percent cover, and standard errors (SE) are shown. NPG = native perennial grass, NAG = native annual grass, XPG = non-native perennial grass, XAG = non-native annual grass, NPF = native perennial forb, NBF = native biennial forb, NAF = native annual forb, XPF = non-native perennial forb, XBF = non-native biennial forb, XAF = non-native annual forb.

2009			2010			2011		
Species	LHG	Mean % cover (± SE)	Species	LHG	Mean % cover (± SE)	Species	LHG	Mean % cover (± SE)
Taraxacum officinale	XPF	1.23 ± 0.62	*Amaranthus tuberculatus*	NAF	1.55 ± 0.43	*Taraxacum officinale*	XPF	4.03 ± 1.29
Potentilla norvegica	NPF	0.34 ± 0.15	*Panicum capillare*	NAG	0.98 ± 0.30	*Amaranthus tuberculatus*	NAF	0.97 ± 0.30
Cyperus esculentus	NPG	0.19 ± 0.11	*Daucus carota*	XBF	0.67 ± 0.25	*Daucus carota*	XBF	0.55 ± 0.21
Zea mays	XAG	0.11 ± 0.04	*Setaria* spp.	XAG	0.61 ± 0.19	*Setaria* spp.	XAG	0.39 ± 0.15
Panicum capillare	NAG	0.07 ± 0.03	*Taraxacum officinale*	XPF	0.59 ± 0.10	*Panicum capillare*	NAG	0.25 ± 0.06
Daucus carota	XBF	0.06 ± 0.03	*Glycine max*	XAF	0.48 ± 0.15	*Potentilla norvegica*	NPF	0.21 ± 0.09
Abutilon theophrasti	XAF	0.06 ± 0.03	*Abutilon theophrasti*	XAF	0.31 ± 0.13	*Oenothera biennis*	NBF	0.18 ± 0.13
Amaranthus tuberculatus	NAF	0.04 ± 0.01	*Medicago lupulina*	XPF	0.19 ± 0.07	*Symphyotrichum pilosum*	NPF	0.11 ± 0.03
Sida spinosa	XPF	0.03 ± 0.02	*Rumex crispus*	XPF	0.11 ± 0.10	*Trifolium hybridum*	XPF	0.07 ± 0.03
Juncus spp.	NPG	0.03 ± 0.02	*Sida spinosa*	XPF	0.11 ± 0.09	*Chenopodium album*	XAF	0.06 ± 0.04

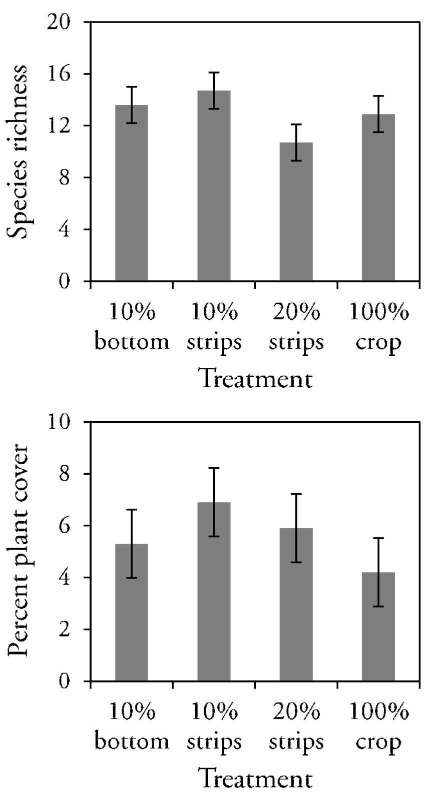

Figure 4. Mean species richness and percent plant cover (±1 SE) of weeds in the crop fields in each treatment during 2009–2011.

Prairie buffer strips became dominated by target perennial, native species within three years of establishment. The relative percent cover of native perennial species increased substantially from 2008 (22%) to 2010 (53%) and remained high in 2011 (58%). This may be attributed to perennial species becoming established and, with time, having competitive advantages over annual species. Similar successional patterns were found in sown grassed margins around cropland throughout England (Critchley et al. 2006) and in reconstructed tallgrass prairies in the USA (Schwartz and Whitson 1987, Rothrock and Squiers 2003, Camill et al. 2004), which tended to shift from annual, weedy vegetation to perennial vegetation within four years of establishment. The plant community within the prairie buffer strips in our experiment followed the same successional trend as those within larger patches of reconstructed prairie reported in previous literature; therefore, buffer strips did not appear to be degraded by their proximity to conventionally managed crops. If the prairie buffer strips continue to follow trends described in other investigations (Schwartz and Whitson 1987, Rothrock and Squiers 2003, Camill et al. 2004), they will have more native and perennial prairie species in subsequent years.

In 2011, 32% of the total plant cover in the prairie buffer strips was non-native perennial species. While some conservationists may perceive non-native perennial species as problematic, we do not consider the coexistence of native and certain non-native perennial species to be problematic, as these species provided year-round ground cover, thereby contributing to the regulation of soil and water movement by the buffer strips. The dominant non-native perennial species in our buffer strips were *Poa compressa* / *P. pratensis* (22% relative cover). In oak savannas, the removal or reduction of the dominant species *P. pratensis* and *Dactylis glomerata* encouraged functionally distinct species (exotic annuals, perennial forbs, and woody plants) rather than functionally similar species, such as native perennial grasses (MacDougall and Turkington 2005). Moreover, *P. pratensis* and *D. glomerata* facilitated seedling survival after moderate disturbance (MacDougall and Turkington 2005). Therefore, we do not consider *P. compressa* / *P. pratensis* to be problematic species or expect native perennial grasses to replace *Poa* if it were removed.

While most of the dominant native species were sown, we recorded a substantial number of plant species within the buffer strips that were not present within the sown mixture of seeds. An additional 133 species, including 90 native species, that were not in the seed mix were identified during the buffer strip vegetation surveys. The buffer strip composition may have differed from seed mix composition because of the presence of viable propagules in the soil, as seeds of many species can persist for up to a few decades (van Diggelen and Marrs 2003). In addition, seeds may have moved into the study sites from neighboring prairie in the Neal Smith National Wildlife Refuge, through water runoff, wind, and animal-vectored dispersal (Saunders et al. 1991, Clark et al. 2002). However, most of the dominant native species in our experiment were sown. Sowing prairie buffer strips—rather than employing natural revegetation techniques for establishment—is likely to be necessary to establish target species. In prairie pothole wetlands, remedial actions such as planting and invasive species control can result in species pools of restored wetlands resembling natural wetlands, while if allowed to revegetate naturally, even sites close to natural wetlands will not develop species pools resembling natural wetlands (Galatowitsch 2006). As with larger plantings, invasive, non-native species are always a risk, but we successfully managed them in our catchments through mowing and spot treatment with systemic herbicides. The lag time from planting to dominance by target plant species that we observed in our prairie buffers is noteworthy, as establishing prairie buffers would not be practical if a land manager does not anticipate keeping them for at least several years.

Table 5. Results of analysis of variance (*F* statistics, *p* values) are presented for the effect of year on the dependent variables of weed species richness and percent plant cover. Mean values for crop fields and their standard errors (SE) for surveys conducted in 2009–2011 are also presented. Numerator degrees of freedom = 2; denominator degrees of freedom = 16; different lowercase letters within rows indicate significant differences among years ($p < 0.05$, Tukey-Kramer adjusted).

	F	*p*	2009 mean	2010 mean	2011 mean
Species richness	24.0	<0.0001	8.4 ± 1.3^{a}	15.4 ± 1.4^{b}	15.1 ± 1.6^{b}
Percent cover	6.7	0.0075	2.4 ± 0.7^{a}	6.5 ± 0.8^{b}	7.7 ± 1.5^{b}

Incorporating prairie buffer strips within crop catchments did not increase the prevalence or influence the composition of weeds in the crops during the four years studied. Our finding agrees with previous studies indicating that non-cropped areas adjacent to crops do not cause weed problems, and may even result in lower weed populations in crop edges (Marshall 2009). Research shows that most species in crop field boundaries are not found in the crop, and oftentimes species in both the field boundary and crop are only in the first two to five meters of the crop or are annuals originating in the crop (Marshall 1989, Marshall and Arnold 1995). The higher weed species richness and percent weed cover we recorded in 2010 and 2011 than in 2009 did not appear to be due to plants from the buffer strips migrating to adjacent cropped areas because there were increased weeds in both the catchments containing buffer strips and the 100% crop catchments. Rather, the increase in weeds could be due to the related factors of crop canopy cover at the sampling time (2009 had more days between soybean planting and vegetation surveying than 2011, possibly allowing for a fuller crop canopy and less weed cover in 2009 than in 2011), the timing of herbicide application (in 2009, the crop was surveyed 20–23 days after glyphosate was applied, while in 2010, the crop was surveyed 43–64 days after it was applied, possibly encouraging more weeds), and/or variability in annual weather (in June and July 2009, there was 232 mm of precipitation while in June and July 2010, there was 492 mm of precipitation, possibly encouraging more weeds).

Not only did prairie buffer strips increase catchment plant biodiversity without creating weed problems in adjacent cropped areas, they also reduced soil and nutrient loss from the crop catchments, provided habitat for a greater number of birds and insects, and were aesthetically pleasing (Liebman et al. 2011, Cox 2012, Helmers et al. 2012, X. Zhou et al., Iowa State University, unpublished data). Data from the experimental catchments in 2008–2010 showed that catchments with buffer strips versus 100% crop catchments reduced water run-off by 40%, soil sediment loss by 96%, and N and phosphorus (P) losses in surface run-off by 82% and 86%, respectively (Helmers et al. 2012, X. Zhou et al., Iowa State University, unpublished data).

Farmers may be hesitant to take even 10% of their land out of production. However, they could replace terraces or buffers composed of exotic cool-season grasses commonly used for conservation purposes in the central USA with prairie buffer strips, and could be compensated for doing so through government incentives. The 15-year total cost of prairie buffer strips is estimated between \$892–\$1,349 per hectare, within a Conservation Reserve Program contract and using 2012 Iowa land rental prices (Leopold Center for Sustainable Agriculture 2012). Prairie buffer strips have several advantages over buffers composed of only cool-season grasses. Prairie vegetation includes more sturdy grasses (e.g., the warm-season grasses Indiangrass and big bluestem [*Andropogon gerardii*]), which stand erect against water flow and increase the settling of sediment (Liu et al. 2008), and includes both cool-season and warm-season plants, which provide vegetative cover on the land throughout the growing season. Companion studies conducted as part of the overall STRIPs experiment have found greater bird species richness (Liebman et al. 2011) and greater total seasonal insect predator abundance (specifically soybean aphid predators; Cox 2012) in the prairie buffer strips than in crop areas. Moreover, many plants in the prairie buffer strips were colorful and aesthetically pleasing, potentially improving the aesthetic value of the land (Marshall and Moonen 2002).

Crop production and prevailing farming practices have nearly eliminated native prairie and greatly reduced the amount of perennial vegetation on the Iowa landscape. These widespread vegetation changes have resulted in uniform, simple landscapes, which have multifaceted and negative effects on the functioning of Midwestern ecosystems (for example, ecohydrologic imbalances such as flooding). Our study indicates that seeding prairie into the crop landscape in the form of buffer strips that occupy only 10% of the cropland can successfully reintroduce native, perennial plant species that can provide multiple ecosystem benefits.

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References

Bonham, C.D. 1989. *Measurements for Terrestrial Vegetation*. New York: John Wiley & Sons.

Brummer, C.E. 1998. Diversity, stability, and sustainable American agriculture. *Agronomy Journal* 90:1–2.

Bultena, G.L., M.D. Duffy, S.E. Jungst, R.S. Kanwar, B.W. Menzel, M.K. Misra, P. Singh, J.R. Thompson, A. van der Valk and R.L. Willham. 1996. Effects of agricultural development on biodiversity: Lessons from Iowa. Pages 80–94 *in* J.P. Srivastava, N.J.H. Smith and D.A. Forno (eds), *Biodiversity and Agricultural Intensification: Partners for Development and Conservation.* Washington, DC: The World Bank.

Camill, P., M.J. McKone, S.T. Sturges, W.J. Severud, E. Ellis, J. Limmer, C.B. Martin, R.T. Navratil, A.J. Purdie, B.S. Sandel, S. Talukder and A. Trout. 2004. Community- and ecosystem-level changes in a species-rich tallgrass prairie restoration. *Ecological Applications* 14:1680–1694.

Clark, J.S., B. Beckage, J. Hillerislambers, I. Ibanez, S. LaDeau, J. McLachlan, J. Mohan and M. Rocca. 2002. Plant dispersal and migration. Pages 81–93 *in* H.A. Mooney and J.G. Canadell (eds), *Encyclopedia of Global Environmental Change*. Chichester, England: John Wiley & Sons.

Cox, R. 2012. The use of reconstructed prairies in Iowa's agricultural landscape to increase ecosystem services and move toward multifunctional landscapes. MS Thesis, Iowa State University, Ames, IA.

Critchley, C.N.R., J.A. Fowbert, A.J. Sherwood and R.F. Pywell. 2006. Vegetation development of sown grass margins in arable fields under a countrywide agri-environment scheme. *Biological Conservation* 132:1–11.

Diamond, J.M. and R.M. May. 1981. Island biogeography and the design of natural reserves. Pages 228–252 *in* R.M. May (ed), *Theoretical Ecology: Principles and Applications,* 2nd edition. Sunderland, MA: Sinauer Associates.

Egan, J.F. and D.A. Mortensen. 2012. A comparison of land-sharing and land-sparing strategies for plant richness conservation in agricultural landscapes. *Ecological Applications* 22:459–471.

Eilers, L.J. and D.M. Roosa. 1994. *The Vascular Plants of Iowa*. Iowa City, Iowa: University of Iowa Press.

Foley, J.A., R. DeFries, G.P. Asner, C. Barford, G. Bonan, S.R. Carpenter, F.S. Chapin, M.T. Coe, G.C. Daily, H.K. Gibbs, J.H. Helkowski, T. Holloway, E.A. Howard, C.J. Kucharik, C. Monfreda, J.A. Patz, I.C. Prentice, N. Ramankutty and P.K. Snyder. 2005. Global consequences of land use. *Science* 309:570–574.

Foley, J.A., N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S. Gerber, M. Johnston, N.D. Mueller, C. O'Connell, D.K. Ray, P.C. West, C. Balzer, E.M. Bennett, S.R. Carpenter, J. Hill, C. Monfreda, S. Polasky, J. Rockstrom, J. Sheehan, S. Siebert, D. Tilman and D.P.M. Zaks. 2011. Solutions for a cultivated planet. *Nature* 478:337–342.

Galatowitsch, S.M. 2006. Restoring prairie pothole wetlands: Does the species pool concept offer decision-making guidance for re-vegetation? *Applied Vegetation Science* 9:261–270.

Gomez, K.A. and A.A. Gomez. 1984. *Statistical Procedures for Agricultural Research,* 2nd edition. New York: John Wiley & Sons.

Gotelli, N.J. and A.M. Ellison. 2004. *A Primer of Ecological Statistics*. Sunderland, MA: Sinauer Associates.

Helmers, M.J., X. Zhou, H. Asbjornsen, R. Kolka, M.D. Tomer and R.M. Cruse. 2012. Sediment removal by prairie filter strips in row-cropped ephemeral watersheds. *Journal of Environmental Quality* 41:289–295.

Hirsh, S.M. 2012. Diversifying monoculture crops by incorporating prairie buffer strips. MS thesis, Iowa State University, Ames, IA.

Hoekstra, J.M., T.M. Boucher, T.H. Ricketts and C. Roberts. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letters* 8:23–29.

Jarchow, M. E. and M. Liebman. 2012. Nitrogen fertilization increases diversity and productivity of prairie communities used for bioenergy. *Global Change Biology–Bioenergy*. DOI 10.1111/j.1757-1707.2012.01186.x.

Kruskal, J.B. 1964. Nonmetric multidimensional scaling: a numerical method. *Psychometrika* 29:115–129.

Kunin, W.E. 1997. Sample shape, spatial scale and species counts: implications for reserve design. *Biological Conservation* 82:369–377.

Leopold Center for Sustainable Agriculture. 2012. *A landowner's guide to prairie conservation strips.* Ames, IA: Iowa State University, Leopold Center for Sustainable Agriculture. www.leopold.iastate.edu/sites/default/files/pubs-and-papers/2012-08-landowners-guide-prairie-conservation-strips.pdf

Liebman, M., M.J. Helmers and L.A. Schulte. 2011. Integrating conservation with biofuel feedstock production. Pages 131–142 *in* P. Nowak and M. Schnepf (eds), *Managing Agricultural Landscpaes for Environmental*

Quality II: Achieving More Effective Conservation. Ankeny, IA: Soil and Water Conservation Society.

Liu, X., X. Zhang and M. Zhang. 2008. Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis. *Journal of Environmental Quality* 37:1667–1674.

Lovell, S.T. and W.C. Sullivan. 2006. Environmental benefits of conservation buffers in the United States: Evidence, promise, and open questions. *Agriculture, Ecosystems and Environment* 112:249–260.

MacDougall, A.S. and R. Turkington. 2005. Are invasive species the drivers or passengers of change in degraded ecosystems? *Ecology* 86:42–55.

Marshall, E.J.P. 1989. Distribution patterns of plants associated with arable field edges. *Journal of Applied Ecology* 26:247–257.

Marshall, E.J.P. 2009. The impact of landscape structure and sown grass margin strips on weed assemblages in arable crops and their boundaries. *Weed Research* 49:107–115.

Marshall, E.J.P. and G.M. Arnold. 1995. Factors affecting field weed and field margin flora on a farm in Essex, UK. *Landscape and Urban Planning* 31:205–216.

Marshall, E.J.P. and A.C. Moonen. 2002. Field margins in northern Europe: Their functions and interactions with agriculture. *Agriculture, Ecosystems and Environment* 89:5–21.

Mather, P.M. 1976. *Computational Methods of Multivariate Analysis in Physical Geography*. London, England: John Wiley & Sons.

McCune, B. and J.B. Grace. 2002. *Analysis of Ecological Communities*. Gleneden Beach, OR: MjM Software Design.

Rothrock, P.E. and E.R. Squiers. 2003. Early succession in a tallgrass prairie restoration and the effects of nitrogen, phosphorus, and micronutrient enrichments. *Proceedings of the Indiana Academy of Science* 112:160–168.

Sala, O.E., F.S. Chapin III, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B.H. Walker, M. Walker and D.H. Wall. 2000. Global biodiversity scenarios for the year 2100. *Science* 287:1770–1774.

Samson, F. and F. Knopf. 1994. Prairie conservation in North America. *BioScience* 44:418–421.

Sustainable Agriculture Network (SAN). 2003. A whole-farm approach to managing pests. College Park, MD: US Department of Agriculture, Sustainable Agriculture Research and Education Program. www.sare.org/Learning-Center/Bulletins/National-SARE-Bulletins/A-Whole-Farm-Approach-to-Managing-Pests

Saunders, D.A., R.J. Hobbs and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: A review. *Conservation Biology* 5:18–32.

Schulte, L.A., M. Liebman, H. Asbjornsen and T.R. Crow. 2006. Agroecosystem restoration through strategic integration of perennials. *Journal of Soil and Water Conservation* 61:164A–169A.

Schwartz, O.A. and P.D. Whitson. 1987. A 12–year study of vegetation and mammal succession on a reconstructed tallgrass prairie in Iowa. *American Midland Naturalist* 117:240–249.

US Department of Agriculture (USDA). 2009. *2007 Census of Agriculture: Iowa State and County Data, Vol. 1: Geographic Area Series.* USDA National Agricultural Statistics Service. www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Iowa/iav1.pdf

US Department of Agriculture, Natural Resources Conservation Service (NRCS). 2012. The PLANTS Database. Greensboro, NC: National Plant Data Team. www.plants.usda.gov

van der Meulen, H.A.B., G.R. de Snoo and G.A.A. Wossink. 1996. Farmers' perception of unsprayed crop edges in the Netherlands. *Journal of Environmental Management* 47:241–255.

van Diggelen, R. and R.H. Marrs. 2003. Restoring plant communities—Introduction. *Applied Vegetation Science* 6:106–110.

With, K.A. 2004. Assessing the risk of invasive spread in fragmented landscapes. *Risk Analysis* 24:803–815.

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