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RESEARCH

Weed Biomass and Species Composition as Affected by an Integrated Crop–Livestock System

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ABSTRACT

Crop and livestock production are rarely integrated together in modern farming systems. Reintegrating crops with livestock production has been shown to produce many agronomic and environmental benefits. The objective of this study was to evaluate how an integrated crop–livestock system would influence weed biomass and weed species composition compared with a conventional, continuous corn (*Zea mays* L.) cropping system. The experimental farming system used in this study was established on a 90-ha site near Pana, IL, in 2002. The integrated system included two phases: (i) a corn and oat (*Avena sativa* L.) cash crop rotation, grown in summer, and (ii) post-harvest grazing of corn stover with annual cover crops. Over a 4-yr period (2004–2007), weed biomass was approximately 4.5 times higher in the conventional system (8.4 g m^{-2}) compared with the integrated system (1.8 g m^{-2}). Weed species composition was affected by the integrated system and showed a temporal disjunction between the time of year and weed life history. Surprisingly, cattle grazing on cropland had little effect on weed biomass or species composition. The primary drivers that suppress weed biomass and change species composition appear to be use of crop rotation and annual cover crops within the integrated system. Wider adoption of integrated crop–livestock systems, such as the one used in this study, should reduce reliance on herbicides compared with more conventional cropping systems.

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Abbreviations: CC, continuous corn; C-CR, corn–corn residue; G-CP, grain–cropland pasture; O-WF, oat–winter forage.

Agricultural production in the United States and Europe has changed dramatically in the last 60 yr. One significant change has been replacement of many small, diversified farms with large, specialized farming operations. With this change, the production of crops and livestock has become decoupled in most agricultural ecosystems (de Wit et al., 1987; Russelle et al., 2007; Sulc and Tracy, 2007). The separation of crop and livestock production is a modern trend made possible by great advances in agricultural technology and readily available agrochemicals. While greatly productive, intensive production in modern crop and livestock systems contributes to various forms of environmental degradation, including eutrophication (McIsaac et al., 2001), soil erosion (Karlen et al., 1994), groundwater contamination (Spalding and Exner, 1993), greenhouse gas emissions (Lal et al., 1999), and worsening pest problems (Levine and Sadeghi, 1991; Porter et al., 2001; Trainer et al., 2005). Research on integrated crop and livestock systems has found them to be highly productive and environmentally sustainable (Allen et al., 2005, 2007; Russelle et al., 2007). This productivity often reflects improved soil structure and fertility, weed suppression, and disruption of pest cycles created by diverse crop sequences and livestock presence (Entz et al., 2002; Humphreys, 1994; McKenzie et al., 1999; Tracy and Zhang, 2008).

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Weeds can be suppressed by cropping system diversification and the reintegration of crop and livestock production (Liebman and Davis 2000; Gallandt et al., 1998, 1999); however, considerably more research has been focused on the former topic than on the latter. Diversified crop rotations have been found to reduce weed population density with crops in a variety of production systems (Mertens et al., 2002; Anderson 2003; Liebman et al., 2008). The impact of crop–livestock integration on weed management has been studied through application of organic soil amendments (e.g., composted manure) to arable fields. These studies found improved crop tolerance of weed interference (Liebman et al., 2004) and greater weed suppression (Gallandt et al., 1998; Hatcher and Melander, 2003). Growers must also remain aware, however, of the possibility of stimulating nitrophilic weeds, such as *Amaranthus rudis* Sauer, with excessive soil N fertility (Menalled et al., 2004). Studies of crop–livestock integration rarely examine the direct effect of livestock grazing on weed growth (but see Mayton et al., 1945), and to our knowledge, have left unexplored the interaction between livestock grazing and crop rotation on weed management outcomes.

In 2002, a 5-yr, integrated crop–livestock farming system experiment was initiated at the University of Illinois. The overarching goal of the study was to compare an integrated crop–livestock system with a field crop production system more typical of the north central region of the United States in terms of agronomic performance and environmental protection. Many variables were measured in this study, including crop and forage yield, forage quality, animal performance, soil fertility, insect diversity, and weed populations. This paper focuses on weed data collected from the farming systems experiment. The objective of this specific study was to determine how the integrated crop–livestock system would affect weed biomass and weed species composition compared with a conventional, continuous corn (*Zea mays* L.) cropping system. We hypothesized that the integrated system would show reduced weed biomass and exhibit a shift in weed species composition compared with a continuous system.

MATERIALS AND METHODS

Site Description

Descriptions of the study site and experiment have been made elsewhere (Sulc and Tracy, 2007; Tracy and Zhang, 2008), and this information will be summarized here. The study site was located near Pana, IL, on the University of Illinois Dudley Smith Research Farm (39°39′ N, 89°08′ W). In 2002, the 90-ha farm was converted to a replicated farming system integrated with cash grain crops, cropland pasture crops, perennial pastures, and beef cattle. The Dudley Smith Research Farm had been in a corn–soybean [*Glycine max* (L.) Merr.] rotation for at least 10 yr before 2002. Weather data was taken from a nearby weather station (5 km) at Pana, IL, maintained by Illinois State Climatologist and the Illinois State Water Survey (Table 1). Soils at the farm consist of silty clay loams, classified as fine, smectitic, mesic vertic Argiaquolls, and are of the Virden series. Baseline soil data collected in 2002 (0- to 15-cm depth) showed a pH range of 5.7 to 6.6, and P and K averages of 32 and 152 mg kg^{-1}, respectively. Based on soil test results from the baseline samples, limestone, P, and K were applied to individual cropping sequence plots before the start of the experiment.

Farming Systems Experiment

Data collection from the farming system experiment started in the fall of 2003 and continued through 2007. The experiment was split into three, 30-ha replicate plots. Each replicate consisted of the following crop sequences: (i) grain–cropland pasture (G-CP) that produced cash grain crops in the summer, and forage and/or crop stover for cattle in winter (19 ha), (ii) a conventional continuous corn (CC) monoculture that is not grazed by cattle (2 ha), and (iii) perennial grasslands composed of cool and warm-season species (8 ha) used to provide forage for cattle during the growing season. For this study, only the annual crop phases of the experiment (G-CP and CC) were sampled for weed biomass.

Each plot containing the G-CP cropping sequence was split into two halves (9.5 ha each). The halves were split into an oat–winter forage (O-WF) phase and a corn–corn residue (C-CR) phase, respectively (Table 2). Crop phases (O-WF and C-CR) were rotated between each half of the plot annually. The O-WF phase was a spring oat (*Avena sativa* L.) crop harvested for grain, followed by a cool-season annual forage mixture of oat, cereal rye (*Secale cereale* L.), and turnip (*Brassica* spp.), which were grazed during the winter (Table 2). The C-CR phase consisted of a corn crop harvested for grain, followed by winter grazing of the remaining corn stover (Table 2). For

Table 1. Total precipitation and mean air temperature recorded near the Dudley Smith Research Farm (Pana, IL).

	Total precipitation							Mean air temperature					
Month	2002	2003	2004	2005	2006	50-yr mean		2002	2003	2004	2005	2006	50-yr mean
	cm							°C					
Jan.	5	1	10	19	5	6		1	–5	–3	–1	4	–3
Feb.	6	3	2	5	1	6		2	–2	–1	2	0	0
Mar.	11	7	13	4	15	8		4	6	8	4	6	6
Apr.	15	6	2	5	10	10		13	13	13	14	14	12
May	29	17	17	4	10	11		16	16	20	17	17	18
June	16	8	8	4	8	11		24	20	21	24	23	23
July	5	17	12	11	8	10		26	25	23	25	26	25
Aug.	4	7	9	6	8	9		25	25	21	25	25	24
Sept.	6	21	0	9	2	8		22	18	21	22	19	20
Oct.	6	5	13	5	8	7		12	13	13	14	11	13
Nov.	2	18	13	11	3	9		5	8	8	8	8	6
Dec.	3	7	7	7	10	7		1	2	0	–3	3	0
Total	109	117	107	89	87	102	Mean	13	12	12	13	13	12

the G-CP crop phases, conventional tillage via chisel plowing and field cultivation in spring was used to prepare the seedbed. The oat crop was planted in early April at a rate of 59 kg ha^{-1} with 0.17-m row spacing and a target population of 400,000 plants ha^{-1}. The oat crop was fertilized at planting with urea at a rate of 60 kg N ha^{-1}, and no herbicide was applied to these plots. Once the oat crop reached maturity in July it was harvested for grain. Soils were then disked to create a clean seedbed and seeded with a winter annual forage mixture of oat, cereal rye, and turnip, at rates of 70, 80, and 8 kg ha^{-1}, respectively. Corn planted in the C-CR cropping sequence was seeded with a Roundup Ready corn hybrid with a target population of 75,000 plants ha^{-1} and 76-cm row spacing. Corn was planted during the first 2 wk of May. Urea was applied before planting and then again at the V6 growth stage, via sidedress, accumulating 150 to 190 kg applied N ha^{-1}. An application of glyphosate isopropylamine salt herbicide (1.12 kg a.i. ha^{-1}) was applied to corn to control weeds each June.

Table 2. Description of crop sequences and management used in the integrated and conventional farming systems.

	Crop sequence	Spring	Summer	Fall	Winter
Integrated crop–livestock system	Oat–winter forage	Conventional tillage, plant oat	Harvest oat	Conventional tillage, plant cover crops	Graze cover crops
	Corn–corn residue	Conventional tillage, plant corn		Harvest for grain	Graze stover
Conventional cropping system	Continuous corn	Conventional tillage, plant corn		Harvest for grain	Fallow

Beef cattle began grazing cropland pastures in November 2003. The perennial pastures were rotationally stocked from spring through fall with warm-season grass pastures filling the midsummer slump of the cool-season pastures. Each fall, cattle were moved from the perennial pastures to the cropland pastures where they had equal access to both halves of the G-CP cropping sequence (corn stover and cover crops). They were stocked at a density of 1 cow ha^{-1} in 2003. The stocking density was slightly lower in subsequent years because several sick cows were removed from the experiment and not replaced. A method of strip grazing was employed to manage cattle through the winter months until forage was depleted. The strip grazing method involved moving a single stand of portable electric fence 25 m every 5 to 10 d, based on depletion of winter forage. In each cropland pasture, cattle had access to an immobile water source, which meant the cattle could not be back-fenced as they strip grazed the cropland pastures. Winter forage supply varied each year usually lasting until late December or February. When winter forage was depleted, cattle were fed hay and grain in dry pasture lots that were not part of the experiment.

Weed Sampling

Weed biomass and species composition were measured in the two crop phases of the integrated system (O-WF and C-CR) and in continuous corn system (CC). Weed sampling was conducted at three times (fall, spring, and summer) from 2004 to 2007. Within each experimental unit, all vegetation in eight 0.5-m^2 quadrats was clipped to ground level, bagged by species and dried in a forced air oven at 65°C to constant mass. Sampling stations were located at least 50-m apart to provide independent subsamples. Species presence or absence and the biomass were combined across subsamples within each experimental unit to form a composite sample. Sampling stations were located across the larger plot such that they would be grazed at the same time during the strip grazing progression. In this way, sampling stations across the three replications experienced a similar stocking density. Because the strips were not back-fenced, cattle traveled through plots multiple times to get to the water source. Our placement of exclosures, then, means they likely experienced a similar exposure to cattle over winter.

Presence of annual cover crops was expected to suppress weed growth in the integrated cropping system (Teasdale, 1996). We hypothesized, however, that grazing cover crops during winter might hinder their ability to suppress winter annual weed growth and spring emergence of summer annual weeds. To address this issue, we established exclosures to separate cattle activities (grazing and trampling) and fall crop biomass effects on weed abundance. Within each experimental unit, eight 1-m^2 cattle exclosures were established in fall before winter grazing began. Vegetation within exclosures was harvested in spring coinciding with sampling of grazed vegetation (described above). As with grazed samples, vegetation in exclosures was harvested within 0.5-m^2 quadrats that were clipped to ground level, bagged by species, and dried in a forced air oven at 65°C to constant mass.

Statistical Analysis

Weed biomass was evaluated first using a global analysis of variance (ANOVA) in the GLM procedure in SAS (SAS Institute, 2003) with year (2004 through 2007), sampling time (fall, spring, summer), and crop phase (CC, corn, cover crop) as independent variables. To test whether cover crop or corn residue biomass affected weed biomass, an ANOVA with year and crop phase was used. The role of winter grazing on spring weed biomass was evaluated by using ANOVA with year, crop phase (CC, O-WF, and C-CR), and exclosure (grazed and ungrazed) as independent variables. In all cases, if significant interactions among main effects were detected ($P = 0.05$), year or sampling time was analyzed separately. Weed biomass data were square root transformed to normalize variances and mean separations were done using Fisher's Least Significant Difference test ($P = 0.05$).

Shifts in weed community composition were detected through nonparametric MANOVA models including terms for replicate, year, crop phase, and grazing, as well as their higher order interaction terms. Although other hypothesis-testing methods, such as distance-based redundancy analysis (Reberg-Horton et al., 2006) are available for multivariate community analysis, nonparametric MANOVA has been shown to be more robust than other currently available methods (McArdle and Anderson, 2001). Within corn treatments, logistic regression was used to assess risk factors for fall and spring weed presence. Logistic regression allows one to predict a discrete outcome, such as group membership, from a set of variables. In our case, we were trying predict the presence of winter annual weeds (risk factor) in either continuous corn or corn that had been rotated from cover crops. The nonparametric MANOVA and logistic regression models were implemented in the "adonis" package of release version 2.7.1 of the R statistical computing environment (R Development Core Team, 2006).

RESULTS AND DISCUSSION

Global analysis of weed biomass showed a significant year × crop phase interaction (P = 0.04). Sampling time (fall, spring, summer) did not explain variation in weed biomass ($P > 0.05$) nor were there any significant interactions with this variable. Except for 2005, weed biomass in CC was higher than C-CR and O-WF crop phases in the integrated system (Fig. 1). Spring was exceptionally dry in 2005 (Table 1) and this likely reduced weed biomass in CC compared with other years. The O-WF and C-CR phases exhibited consistently low weed biomass especially in 2007 (Fig. 1).

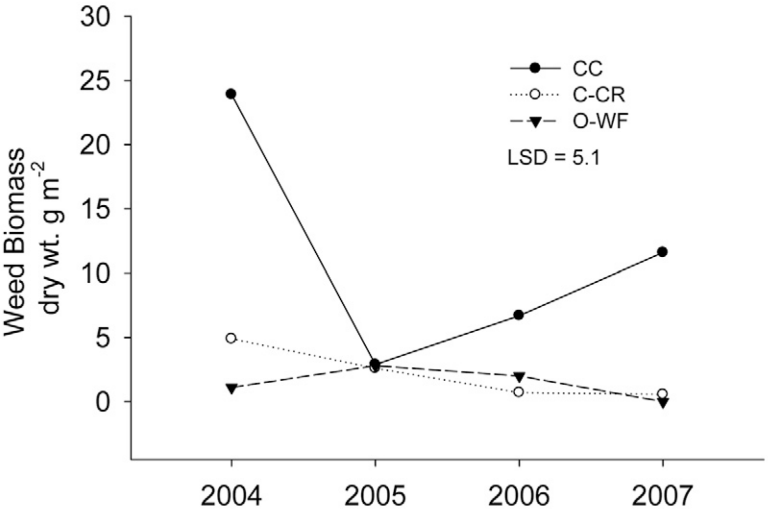

Figure 1. Mean weed biomass, pooled over season, within three crop phases at Dudley Smith Research Farm (2004–2007). CC, continuous corn; C-CR, corn–corn residue; O-WF, oat–winter forage.

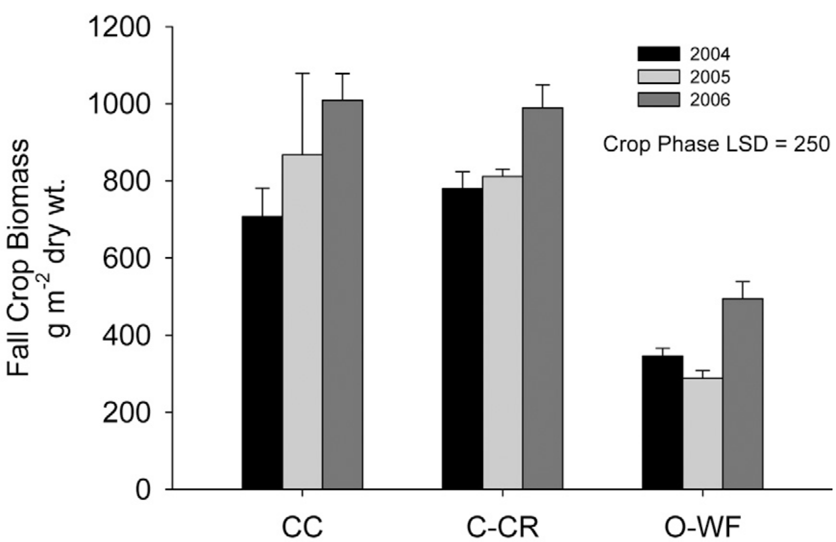

Figure 2. Mean crop biomass measured in fall before winter grazing began. CC and C-CR values are corn stover and O-WF represents dry weight biomass of turnip, oat, and cereal rye mixture. LSD represents comparisons among three crop phases. Error bars are 1 SE. CC, continuous corn; C-CR, corn–corn residue; O-WF, oat–winter forage.

We expected weed biomass would be influenced by annual cover crop or corn residue biomass present in the fall before winter grazing began (Teasdale, 1996). A high amount of crop biomass on plots might be expected to suppress weeds either by shading them, in the case of corn residue, or by competing with weeds for resources (e.g., light, water, nitrogen) like annual cover crops. Fall crop biomass (corn stover or annual cover crop biomass) showed no crop phase × year interaction ($P > 0.05$) so only main effects were considered. Fall crop biomass differed among crop phase treatments ($P < 0.01$) averaging 377 g m^{-2} in O-WF treatments and 859 g m^{-2} in CC and C-CR treatments with corn stover (Fig. 2). Fall crop biomass was greatest in 2006 (831 g m^{-2}) compared with 2004 and 2005, when biomass was 608 and 655 g m^{-2}, respectively.

We used linear regression to evaluate the relationship between fall crop biomass and weed biomass. Fall crop biomass failed to explain variation in weed biomass at all sampling points—fall, spring, or summer ($P > 0.05$).

The results from fall crop biomass analysis showed that corn residue biomass was similar in the integrated and conventional systems. Despite the similarity in residue biomass, weed biomass was highest in the continuous corn system most years (Fig. 1). This result suggests that factors other than residue biomass help suppress weeds in the integrated system.

Much research has shown the value of cover crops at suppressing weeds in various cropping systems (Buhler et al., 1998; Hiltbrunner et al., 2007; Moyer et al., 1994; Norsworthy and Frederick, 2005). Annual cover crops were probably more competitive with weeds for available light and soil nutrients (e.g., N, water) compared with corn stover. The brassica and small grain cover crops used in this study may also have had a phytotoxic effect on weed recruitment and growth (Singh et al., 2003).

A unique aspect of this study is that cover crops were used for cattle forage in fall and winter. We anticipated grazing by cattle would reduce cover crop biomass and possibly allow more weeds to become established within the integrated system. Analysis of the exclosure data showed no significant year × crop phase interactions ($P > 0.05$). Crop phase had a significant effect on spring weed biomass (P = 0.0005) with the corn phases (CC and C-CR) showing higher weed biomass than the O-WF phase (Table 3). Surprisingly, cattle exclusion had no significant effect on weed biomass (P = 0.31). In the C-CR treatments, mean weed biomass was numerically higher when protected from cattle, but the data were highly variable within crop phases (Table 3).

Overall, our results suggest cattle grazing in winter neither increased nor suppressed weed abundance in the integrated system. The presence of annual cover crops and rotation of the crop phases in the integrated system were probably more effective at reducing weed biomass relative to cattle activity. Similar results have been noted in other studies in which crop rotations with forages have been found to effectively suppress weeds (Entz et al., 2002; Ominski et al., 1999; Schoofs and Entz, 2000).

We also evaluated how the different cropping systems influenced species composition of weed communities. Logistic regression analysis of risk factors for fall weed presence showed that it was 2.25 times more likely to find winter annual weeds in the CC treatment than in the C-CR integrated system. Analysis for presence of weeds in the spring, after winter cropland grazing, revealed that it was seven times more likely to find winter annual weeds in the CC and C-CR treatment compared with the O-WF treatment.

Within the integrated system, nonparametric MANOVA indicated a significant crop phase (C-CR and O-WF) by year interaction ($P = 0.01$) for weed species composition measured in fall, but not in spring or summer. The interaction suggests species composition differed between crop phases in fall but not consistently during the 3 yr of this study (data not shown). Spring weed composition in the integrated system differed between C-CR and O-WF phases (Fig. 3), but cattle exclusion had no effect. In spring, *Stellaria media* (L.) Vill., *Barbarea vulgaris* W.T. Aiton, and *Gnaphalium exilifolium* A. Nelson were more common in C-CR. Winter annuals like *Poa annua* L. and *Veronica peregrina* L. occurred more in the O-WF phases. Weed species composition in summer showed no dissimilarity between C-CR and O-WF phases.

We also compared species composition within corn phases of integrated and nonintegrated systems (Fig. 4 and 5). The CC and C-CR treatments showed significant species composition differences at both spring and summer sampling periods ($P = 0.04$), but not in the fall. In spring, winter annuals (e.g., *S. media*) tended to be more important in CC, while summer annuals (*Abutilon theophrasti* Medik., *Chenopodium album* L.) and perennials (*Rumex crispus* L., *Cichorium intybus* L.) established in the C-CR phase (Fig. 4). During summer, summer annuals (e.g., *Solanum nigrum* L., *Hibiscus trionum* L.) occurred more in CC treatments, while winter annuals like *P. annua*, and *Stellaria media* were more common in C-CR (Fig. 5). Within corn phases, it appears the integrated system may have caused a shift in weed species composition toward those winter annuals whose growth can extend into summer.

Cropping system diversification through crop rotation, cover cropping, and grazing may result in weed species shifts and reductions in weed biomass through temporal disruption of weed life cycles (Liebman and Staver, 2001). It may also promote weed species shifts through the emergence

Table 3. Mean weed biomass in spring with cattle excluded (no grazing) or present (grazing).†

	Weed biomass g m^{-2} dry wt.	
	No grazing	Grazing
Continuous corn	9.2 (5.9)	NA
Corn–corn residue	7.7 (6.5)	0.9 (0.4)

†Values in parentheses are 1 SE.

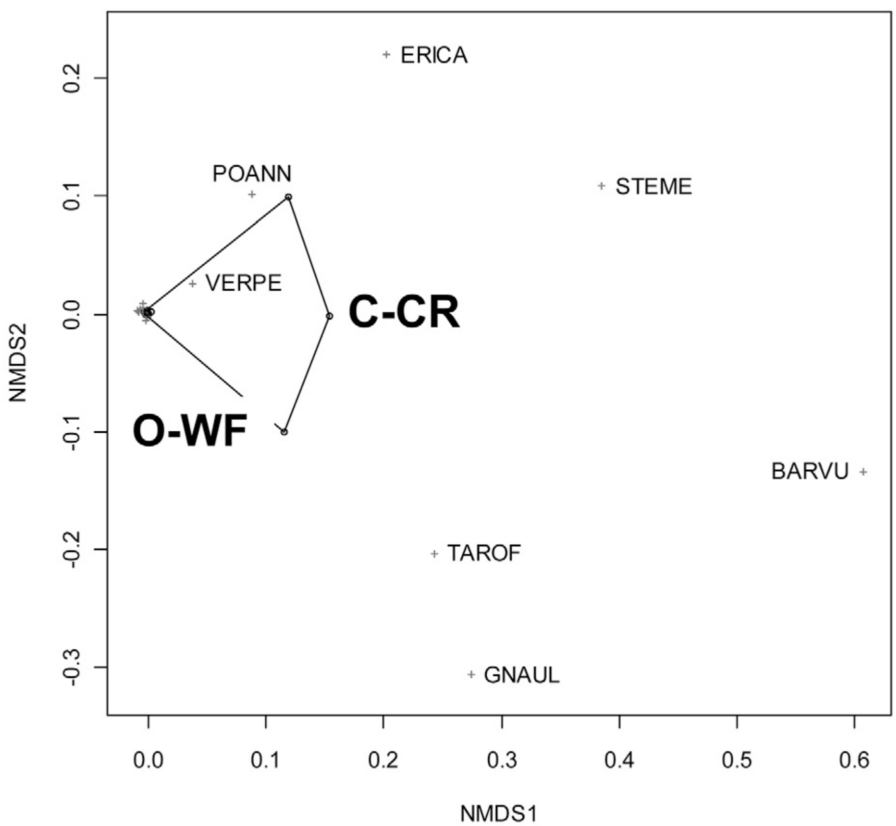

Figure 3. Weed species composition measured in spring (2005–2007) within the integrated crop–livestock system. Graph shows separation, or dissimilarity, in species composition between crop phases (corn–corn residue [C-CR] and oat–winter forage [O-WF]) as indicated by convex hulls containing plots within a given phase within the integrated system. The *x* and *y* axes represent the primary and secondary nonmetric multidimensional scaling (NMDS) ordination axes, respectively. A cluster of points at the left vertex of the polygon are associated with the O-WF system. Only one polygon is shown because the many overlapping species codes made it difficult to add the O-WF polygon on the plot. Species abbreviations: STEME, *Stellaria media*; BARVU, *Barbarea vulgaris*; GNAUL, *Gnaphalium exilifolium*; POANN, *Poa annua*; VERPE, *Veronica peregrina*; ERICA, *Conyza canadensis* (L.) Cronquist; TAROF, *Taraxacum officinale* L.

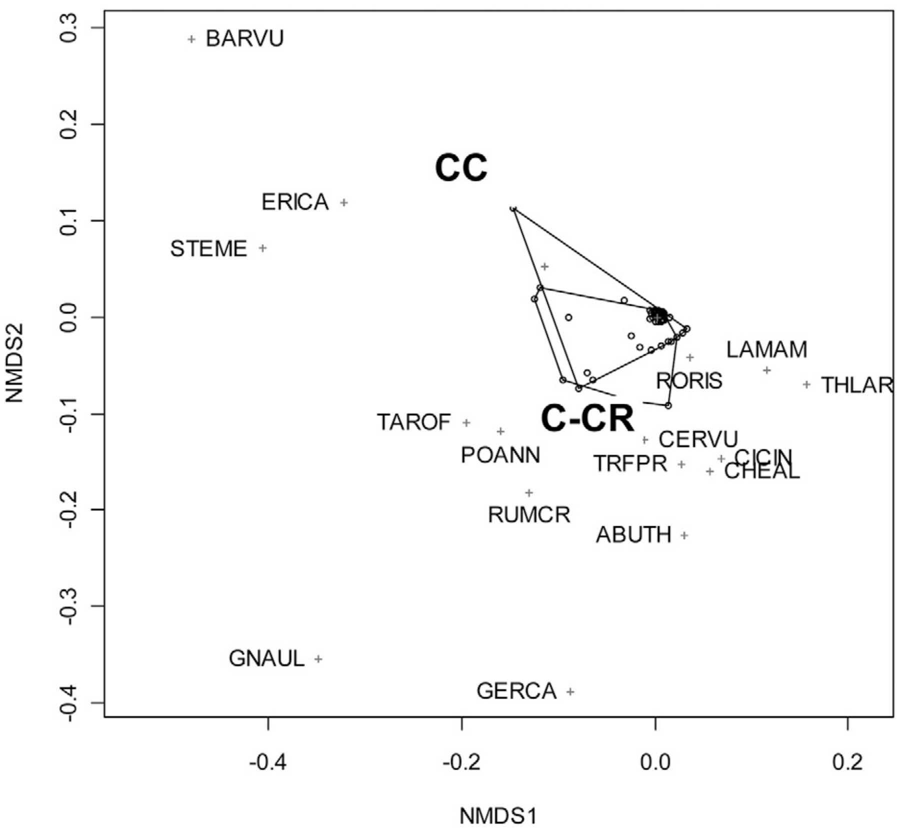

Figure 4. Weed species composition measured in the spring (2005–2007) in continuous corn (CC) and corn–corn residue (C-CR) crop phases of the integrated system. Graph shows separation, or dissimilarity, in species composition between corn phases of integrated (C-CR) and nonintegrated systems (CC) similar to Fig. 3. Species abbreviations not in Fig. 3 include: ABUTH, *Abutilon theophrasti*; RUMCR, *Rumex crispus*; CICIN, *Cichorium intybus*; CHEAL, *Chenopodium album*; THLAR, *Thlaspi arvense* L.; LAMAM, *Lamium amplexicaule* L.; TRFPR, *Trifolium partense* L.; RORIS, *Rorippa islandica* (Oeder) Borbás.

of weeds that are tolerant of existing weed management practices or tillage methods (Ball and Miller, 1993). Both factors may have been operating in our system, with temporal disruptions from varying planting and harvest dates of cash crops, and imposition of weed-suppressive conditions through grazing pressure and shading by cover crops. Weed community shifts have been observed in other integrated crop–livestock system studies. Ominski et al. (1999) found that rotating alfalfa (*Medicago sativa* L.) or alfalfa–grass hay crops with wheat shifted the weed communities away from wild oat (*Avena fatua* L.), green foxtail [*Setaria viridis* (L.) P. Beauv.], and Canada thistle [*Cirsium arvense* (L.) Scop.], but selected for dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers). Reberg-Horton et al. (2006) found that crop rotation synergized the effects of composted beef manure amendments in such a way as to increase cultivation efficacy through improved soil tilth. This, in turn, led to a decrease in components of the weed community vulnerable to cultivation, in contrast to a conventional, less heterogeneous system relying solely on herbicides for weed management. Shifts in weed communities may not always be desirable, as with the rise of herbicide-resistant weed biotypes in a field (Patzoldt et al., 2005); however, cropping system diversification appears to not only disrupt weed communities, but help reduce the dominance of entrenched weed species (Liebman and Staver, 2001).

CONCLUSIONS

This study evaluated how an integrated crop–livestock system affected weed abundance and weed species composition compared with a conventional, continuous corn system. The focal point within the integrated system was use of cropland to provide winter forage for cattle. That forage consisted of annual cover crops and corn stover. The integrated cropping system had large effects on both weed abundance and species composition. Except for an unusually dry year, weed biomass was much lower in the integrated system compared with continuous corn. The integrated system also created a temporal disjunction between the time of year and weed life history. In the integrated system, summer annuals were more abundant in spring and winter annuals in summer when neither could grow optimally. This temporal shift in species composition may have contributed to the lower weed biomass measured in the integrated system. Cattle activities in winter (e.g., grazing, trampling) surprisingly had little influence on weed biomass or species composition. Crop rotation, in general, and presence of annual cover crops, specifically, likely interacted to suppress weeds in the integrated crop–livestock system. Wider adoption of integrated crop–livestock systems, like the one used in this study, should help reduce reliance on herbicides compared with more conventional cropping systems.

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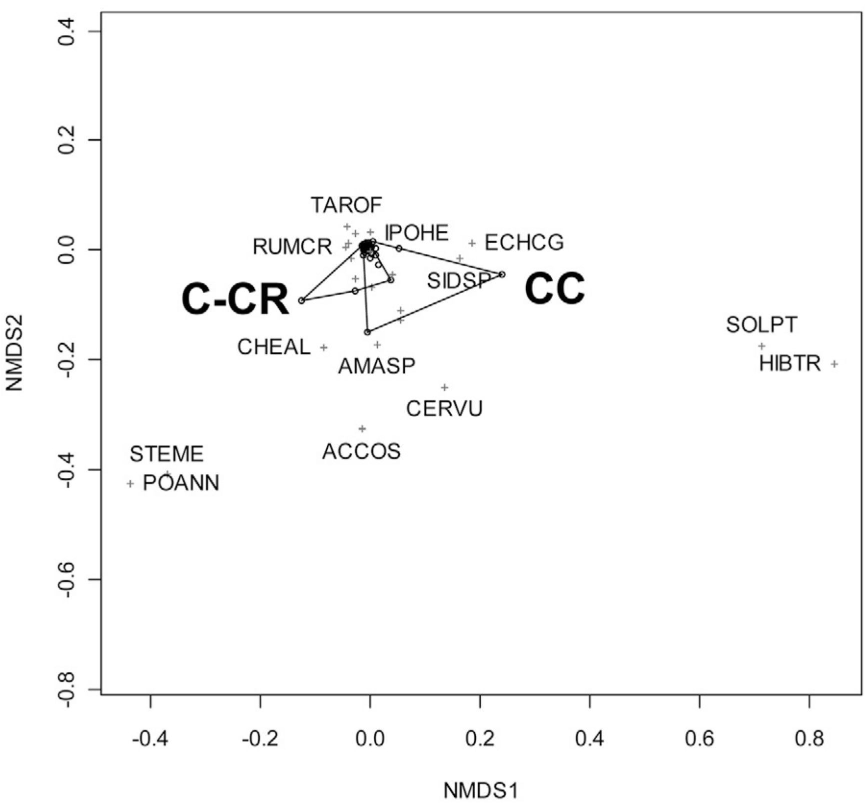

Figure 5. Weed species composition measured in summer (2005–2007) in continuous corn (CC) and corn–corn residue (C-CR) crop phases. Graph shows separation, or dissimilarity, in species composition between corn phases of integrated (C-CR) and nonintegrated systems (CC) as in Fig. 4. Species abbreviations not listed in Fig. 3 and 4 include: SOLPT, *Solanum nigrum*; HIBTR; *Hibiscus trionum*; IPOHE, *Ipomoea hederacea* Jacq.; ECHCG, *Echinochloa crus-galli* (L.) P. Beauv.; AMASP, *Amaranthus* spp.; ACCOS, *Acalypha ostryifolia* Riddell.

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