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Impacts of Rotation Schemes on Ground-Dwelling Beneficial Arthropods

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Crop rotation alters agroecosystem diversity temporally, and increasing the number of crops in rotation schemes can increase crop yields and reduce reliance on chemical inputs. We hypothesized that increased crop diversity within annual rotations would positively affect ground-dwelling beneficial arthropod communities. During 2012 and 2013, pitfall traps were used to measure activity-density and diversity of ground-dwelling communities within three previously established, long term crop rotation studies located in Wisconsin and Illinois. Rotation schemes sampled included continuous corn, a two-year annual rotation of corn and soybean, and a three-year annual rotation of corn, soybean, and wheat. Insects captured were identified to family, and non-insect arthropods were identified to class, order, or family depending upon the taxa. Beneficial arthropods captured included natural enemies, granivores, and detritivores. Beneficial communities from continuous corn plots were significantly more diverse compared to those from two-year annual rotation, while communities from three-year annual rotation did not differ from either rotation scheme. However, no differences were detected among rotation schemes in either corn or soybean plots for total community activitydensity or activity-density of any individual taxa. Crop species within all three rotation schemes were annual crops, and are associated with agricultural practices that make infield habitat subject to anthropogenic disturbances and temporally unstable. Habitat instability and disturbance can limit the effectiveness and retention of beneficial arthropods, including natural enemies, granivores, and detritivores. Increasing non-crop and perennial species within landscapes in conjunction with more diverse rotation schemes may increase the effect of biological control of pests by natural enemies.

Keywords

Community composition, IPM, natural enemies, NMDS, pitfall traps

Disciplines

Agriculture | Biodiversity | Entomology | Terrestrial and Aquatic Ecology

Comments

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Impacts of Rotation Schemes on Ground-Dwelling Beneficial Arthropods

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Abstract

Crop rotation alters agroecosystem diversity temporally, and increasing the number of crops in rotation schemes can increase crop yields and reduce reliance on chemical inputs. We hypothesized that increased crop diversity within annual rotations would positively affect ground-dwelling beneficial arthropod communities. During 2012 and 2013, pitfall traps were used to measure activity-density and diversity of ground-dwelling communities within three previously established, long term crop rotation studies located in Wisconsin and Illinois. Rotation schemes sampled included continuous corn, a two-year annual rotation of corn and soybean, and a three-year annual rotation of corn, soybean, and wheat. Insects captured were identified to family, and non-insect arthropods were identified to class, order, or family depending upon the taxa. Beneficial arthropods captured included natural enemies, granivores, and detritivores. Beneficial communities from continuous corn plots were significantly more diverse compared to those from two-year annual rotation, while communities from three-year annual rotation did not differ from either rotation scheme. However, no differences were detected among rotation schemes in either corn or soybean plots for total community activity-density or activity-density of any individual taxa. Crop species within all three rotation schemes were annual crops, and are associated with agricultural practices that make infield habitat subject to anthropogenic disturbances and temporally unstable. Habitat instability and disturbance can limit the effectiveness and retention of beneficial arthropods, including natural enemies, granivores, and detritivores. Increasing non-crop and perennial species within landscapes in conjunction with more diverse rotation schemes may increase the effect of biological control of pests by natural enemies.

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Introduction

Arthropods provide many types of ecosystem services, including biological control of pests (Losey and Vaughan 2006). Greater natural enemy abundance has been hypothesized as a potential explanation for reduced pest abundance in diversified agroecosystems (Root 1973, Andow 1991). Increasing the number of crops in rotation would correspondingly increase agroecosystem diversity. This is particularly needed in areas dominated by monoculture production of corn and soybean, such as the U.S. Corn Belt (USDA, NASS 2015).

Crop rotation is associated with numerous agronomic benefits. The risk of soil-borne pathogens can be reduced if crop rotations include non-host plants (Ratnadass et al. 2012), and some crop species can increase water and nutrient use efficiency for other crops following in rotation (Anderson 2005). Annual rotation of corn (*Zea mays* L.) and soybean (*Gylcine max* L.) can significantly increase corn yield compared to corn planted continuously, even when continuous corn receives greater rates of fertilizers and pesticides (Bullock 1992). Adding crops to rotation schemes can further increase yields and reduce reliance on chemical inputs (Smith et al. 2008); e.g., conventionally managed corn and soybean in a two-year rotation was not as profitable or productive as an extended three-year rotation that added non-harvested small grains (oat (*Avena sativa* L.) or spring triticale (*Triticosecale* L.)) or a four-year rotation that added small grains and alfalfa (*Medicago sativa* L.) (Davis et al. 2012).

The response of natural enemies to greater diversity of crops within annual rotations can vary. Rusch et al. (2013) measured how landscape complexity and crop rotation intensity affected biological control of *Rhopalosiphum padi* L. (Hemiptera: Aphididae) on barley (*Hordeum vulgare* L.). Results indicated that biological control of *R. padi* increased with greater landscape complexity independent of the intensity of crop rotation, however, increased crop rotation functioned to stabilize the level of biological control. One of the most well studied natural enemies in agroecosystems are Carabidae (Coleoptera); a diverse family composed of many predator, granivores, and omnivorous species (Kromp 1999). In one case, species richness and activity-density of Carabidae were significantly greater in a low input, four-year rotation of corn, soybean, triticale, and alfalfa compared to a conventionally managed two-year rotation of corn and soybean (O'Rourke et al. 2008). In another case, diversity and evenness of Carabidae species was greater within continuous corn and a two-year corn and soybean rotation compared to and a four-year corn, soybean, wheat (*Triticum aestivum* L.), and alfalfa rotation (Ellsbury et al. 1998).

Low crop diversity and increased farming efficiency together limit the heterogeneity of crop management practices and promote temporal uniformity among fields (Benton et al. 2003). Management practices associated with annual crops (i.e., planting, tillage, harvesting, pesticide applications) regularly disturb habitat and disrupt the effectiveness of natural enemies (Altieri 1999, Landis et al. 2000) and other types of beneficial arthropods, including granivores and detritivores (Robertson et al. 1994, Cromar et al. 1999, Baraibar et al. 2009). The goals of this study were to quantify the effects of crop diversity in annual rotation schemes on the composition of ground-dwelling beneficial arthropods. We hypothesized that rotation schemes that included greater crop diversity would positively affect beneficial arthropod communities and individual taxa. To test this hypothesis, pitfall traps were used to measure the activity-density of arthropods found in plots of corn without rotation, corn and soybean in a two-year annual rotation, and corn and soybean in a three-year annual rotation of corn, soybean, and wheat.

Materials and Methods

Field Sites and Experimental Design. Data were collected during 2012 and 2013 from three locations; the University of Wisconsin Arlington Agricultural Research Station (Arlington, WI; 42º18′ N, 89º20′ W), the University of Wisconsin Lancaster Agricultural Research Station (Lancaster, WI; 42º49′ N, 90º47′ W), and the Northwestern Illinois Agricultural Research and Demonstration Center (Monmouth, IL; 40º55′ N, 90º43′ W). Experimental plots were established to study the long term effects of crop rotation beginning at Arlington in 1986 (Lund et al. 1993, Pedersen and Lauer 2002), at Lancaster in 1966 (Stanger et al. 2008), and at Monmouth in 1996 (Zuber et al. 2015). Plot sizes were 18.2 m × 18.2 m, 6.1 m × 9.1 m, and 22 m × 12 m for Arlington, Lancaster, and Monmouth, respectively. Continuous corn, corn and soybean in a two-year annual rotation, and corn, soybean, and wheat in a three-year annual rotation were grown at each location and replicated in randomized complete block design. Each crop within the three rotation schemes was present within each block, at all locations every year. Plots were adjacent within blocks, and blocks were separated by 3 m, 22 m, and 12 m grass alleyways at Arlington, Lancaster, and Monmouth, respectively.

Arthropod Sampling. At each location, six corn and four soybean plots were sampled. Ground-dwelling arthropods were sampled from two plots per crop per rotation scheme; 1) continuously planted corn, 2) two-year annually rotated corn and soybean (both crops sampled), and 3) three-year annually rotated corn, soybean, and wheat (corn and soybean sampled). Plots were sampled four times each year, and sampling dates were designated as June, July, August, and September. During 2012, Arlington and Lancaster were sampled on 3 July, 26 July, 16 Aug., and 6 Sept. and Monmouth was sampled on 5 July, 24 July, 14 Aug., and 4 Sept. In 2013, Arlington and Lancaster were sampled on 25 June, 13 July, 13 Aug., and 13 Sept. and

Monmouth was sampled on 23 June, 24 July, 15 Aug., and 11 Sept. Sample dates 3 July at Arlington and Lancaster and 5 July at Monmouth were grouped with June sampling dates for all analyses. By crop, 144 corn plots (2 years × 3 locations × 3 rotation schemes × 4 sampled dates × 2 plots) and 96 soybean plots (2 years × 3 locations × 2 rotation schemes × 4 sampled dates × 2 plots) were sampled.

Three pitfall traps were placed within each plot for 24 hrs to estimate the activity-density of ground-dwelling arthropods. Pitfall traps were 1 L cups (Reynolds Food Packaging, Shepherdsville, Kentucky) buried in the ground flush with the soil surface. Traps were filled with ca. 100 mL of non-scented, soapy water solution to prevent arthropods from escaping. To avoid debris entering pitfall traps, a cover raised ca. 5 cm above the soil surface was placed above each trap (Hummel et al. 2012). Pitfall traps remained in plots for 24 h during each sampling period. The recovered contents of pitfall traps were placed separately into sealable plastic bags and stored in freezers until contents were sorted. Taxa classified as beneficial included natural enemies of pests, granivores, and detritivores. Beneficial insects captured in pitfall traps were identified to family, and beneficial non-insect arthropods were identified to class, order, or family depending upon the taxa (Table 1).

Statistical Analysis. In all cases, data were analyzed separately by crop. Taxa were only included in analyses if they composed > 1% of the total number of individuals captured. Activity-density data were analyzed with nonmetric multidimensional scaling (NMDS), multivariate analysis of variance (MANOVA), and analysis of variance (ANOVA). Additionally, diversity indices, Simpson's index and Simpson's evenness index, were analyzed with ANOVA. Factors tested included rotation scheme, sampling date, the interaction of rotation scheme and sampling date, year, and location. For corn, these rotation schemes were continuous corn, corn in two-year annual rotations and corn in three-year annual rotations. For soybean, rotation schemes included soybean in two-year annual rotations and soybean in three-year annual rotations.

Nonmetric multidimensional scaling was conducted using the vegan package in R 3.1 statistical software (Dixon 2003, Oksanen 2013, R Core Team 2014). The NMDS summarizes the relationships among all variables and displays these relationships in ordination space. Each point within the NMDS represents the composition of a community, and composition becomes increasingly similar as distances among points within the NMDS decreases. The metaMDS function was used to create NMDS ordination plots with Sorensen (Bray-Curtis) distances (Krebs 1999). Stress (*S*) and non-metric fit (r^2), statistics measuring goodness of fit of the NMDS ordination distances to the data dissimilarity, were also computed (Oksanen 2013). The envfit function was used to create centroids of mean community composition for each combination of rotation scheme by sampling date as well as create vectors describing changes in activity-density of individual taxa (Oksanen 2013). The vector direction indicates an increase in activity-density for a taxon. The significance of each vector was calculated from 999 random permutations of these data (Oksanen 2013).

Activity-density of taxa was analyzed with a repeated-measures MANOVA that included rotation scheme, sampling date, and their interaction (PROC GLM, SAS statistical software version 9.3, SAS Institute, Cary, North Carolina). The repeated-measures analysis was based on a split-plot design (Quinn and Keough 2002). Data were transformed with the function log (x + 1) to increase the normality of the residuals. Fixed effects were rotation scheme, sampling date, the interaction of rotation scheme and sampling date. Random effects were year, location, the interaction of year and location, plot nested within the interaction of year × location × rotation scheme, and sampling date × plot nested within year × location × rotation scheme.

Activity-density of total beneficial arthropods, activity-density of individual taxa and diversity indices were analyzed using repeated-measures ANOVA (PROC MIXED) in SAS 9.3. Simpson's index (*D)* was calculated as $D = 1 / (\sum p_i^2)$ where p_i is the proportion of individuals of species *i* among the total individuals collected (Magurran 2004). The Simpson's evenness index ($E_{1/D}$) was calculated as $E_{1/D} = (1/D) / S$ where *S* is the number of taxa collected (Magurran 2004). To meet the assumptions of the ANOVA, activity-density data were transformed by the log (x + 1) function. Rotation scheme, sampling date, and their interactions were classified as fixed effects. Random effects included year, location, the interaction of year and location, plot nested within the interaction of year × location × rotation scheme, and sampling date × plot nested within year × location × rotation scheme. When significant effects were present, pairwise comparisons were made using the PDIFF option (in PROC MIXED). Alpha levels were adjusted for multiple comparisons using the Bonferroni correction.

Results

Cumulatively over both study years, pitfall traps collected over 3,700 and 2,400 individual beneficial arthropods from corn and soybean plots, respectively. For both corn and soybean, the same six taxa each represented > 1% of all individuals captured (Table 1). The vast majority of beneficial individuals collected from both corn and soybean plots were Carabidae and Formicidae.

Low stress solutions were found for NMDS ordinations for corn plots (*S* = 0.09; Fig. 1A) and soybean plots (*S* = 0.07; Fig. 2A), and distances within ordinations were highly correlated to pitfall trap data dissimilarity (non-metric fit r^2 = 0.991 and 0.994 for corn and soybean data, respectively). Community composition in both corn and soybean plots were not significantly affected by rotation scheme when tested by MANOVA, yet the composition of both communities did change significantly over time (Table 2; Figs. 1B and 2B). Rotation scheme also did not affect total activity-density in epigeal communities captured from corn or soybean plots when test with ANOVA, but sampling date did significantly affect total activity-density in both crops (Tables 3 and 4). Total activity-density in corn and soybean was significantly greater when sampled in June and lowest in August (Figs. 1B and 2B).

Activity density for individual taxa was not significantly affected by rotation scheme, though there was a marginal effect of rotation scheme on the activity-density of Carabidae captured from corn plots (Tables 3 and 4). Activity-density of Carabidae was numerically greatest in annually rotated corn and lowest in corn within three-year annual rotations (Table 4).

Sampling date significantly affected activity-density of nearly all taxa (Table 3). Carabidae was the most frequently captured arthropod in pitfall traps (Table 1), and their activity-density was greatest when sampled during June and July. Though the seasonal pattern of Carabidae activity-density was similar in both corn and soybean plots, there were only significant differences among sampling dates when Carabidae were sampled in corn (Table 3; Figs. 1B and 2B). Formicidae also were common in both corn and soybean communities (Table 1). Activity-density of Formicidae in corn plots peaked during July and waned as the season progressed (Fig. 1B). In soybean plots, activity-density of Formicidae peaked in June, declined through August, and increased during September (Fig. 2B). Analysis of Gryllidae showed that their activity-density changed significantly over time in both corn and soybean plots (Table 3), however only corn plots had significant pairwise comparisons among sampling dates after adjusting alpha levels for multiple comparisons. Activity-density of Gryllidae in corn plots was greatest during September and lowest during June (Fig. 1B). Activity-density of Opiliones differed by sampling date in soybean plots (Table 3), with capture in pitfall traps the lowest during June and greatest during July sampling (Fig. 2B). In both corn and soybean plots, activity-density of Lycosidae was significantly higher when sampled during June and then declined as sampling continued throughout the year (Table 3; Figs. 1B and 2B). Activity-density of Diplopoda contrasted with that of Lycosidae, as Diplopoda activity-density was significantly greatest when sampled during September (Table 3; Figs. 1B and 2B).

Vectors describing changes in activity-density of individual taxa from both crops were all significantly correlated to NMDS ordinations (Table 5). In corn and soybean ordinations, changes in activity-density of Carabidae, Formicidae, Gryllidae and Opiliones were better represented by the NMDS ordinations than were Lycosidae and Diplopoda (Table 5). Gryllidae and Formicidae vectors in both corn and soybean NMDS were consistent with their corresponding activity-density (i.e., activity-density of Formicidae was greatest when sampled earlier in the season and the Formicidae vectors move towards the early season sampling date centroids in both NMDS). However, not all vectors matched the activity-density patterns of their corresponding taxa. For example, Carabidae in corn plots were captured in significantly greater frequency during July compared to September (Fig. 1B), but the vector describing changes in Carabidae activity-density in the NMDS moves directly away from all July and September community centroids (Fig. 1A).

Simpson's index differed significantly among rotation schemes in corn plots ($F = 5.18$; df = 2, 28; $P = 0.012$), but did not differ between soybean in two-year or three-year annual rotation ($F = 0.12$; df = 1, 17; $P = 0.73$). Communities in continuous corn plots were significantly more diverse compared to those in two-year annual rotations, while diversity within three-year annual rotations did not differ from any rotation scheme (Table 6). Values of *D* also different significantly by sampling data for both corn ($F = 5.60$; df = 3, 93; $P = 0.0014$) and soybean ($F = 3.26$; df = 3, 58; $P = 0.028$). Corn plots sampled in September were significantly more diverse compared to plots sampled during July and August (Table 6). Diversity significantly differed in soybean plots only between July and September sampling dates (Table 6). Simpson's evenness did not differ among rotation schemes in corn ($F = 0.73$; df = 2, 28; $P = 0.49$) or soybean ($F = 0.03$; df = 1, 17; $P = 0.03$), and did not differ among sampling dates in corn ($F = 2.34$; df = 3, 93; $P = 0.078$) or soybean ($F = 1.50$; df = 3, 58; $P = 0.22$) (Table 6).

Discussion

The objective of this study was to measure the effects of crop diversity in annual rotation schemes on the composition of ground-dwelling beneficial arthropods. From two years of data, we observed significant differences in arthropod diversity among rotation schemes as measured by Simpson's index. Ground-dwelling arthropod communities from continuous corn plots were significantly more diverse compared to communities sampled from two-year annual rotations (Table 6). However, no differences were detected among rotation schemes in either corn or soybean plots for total community activity-density (Table 3) or when community composition was compared by MANOVA (Table 2). Furthermore, activity-density of individual taxa were not affected by rotation scheme (Tables 3 and 4). These data did not support our hypothesis that rotation schemes with greater crop diversity would positively affect ground-dwelling communities and individual taxa. Instead, sampling date affected community composition and individual taxa in both corn (Fig. 1B) and soybean plots (Fig. 2B).

Carabidae and Formicidae were the most frequently captured taxa throughout the course of the study (Table 1). Significantly greater diversity during September (Table 6) can be partially attributed to significant decreases in Carabidae and Formicidae individual activity-densities sampled later in the year (Figs. 1B and 2B). However, neither taxa's activity-density was affected by differing crop diversity in annual rotation (Table 4). Within both Carabidae and Formicidae, species can belong to different or multiple functional groups. Formicidae are omnivorous and can function as granivores, predators, and detritivores within cropping systems (Inouye et al. 1980, Dively and Rose 2003, Bhatti et al. 2005, Baraibar et al. 2009). Carabidae are a diverse family with species that can be classified as generalist predators, granivores, andomnivores (Kromp 1999). Although Carabidae community activity-density and species richness have been observed to increase with increasing diversity within crop rotations and reduced disturbance regimes (O'Rourke et al. 2008), species do not respond uniformly (Bertrand et al. 2016). In a comparison of Carabidae activity-density and community composition among conventional, no-tillage, and organically managed fields, total activity-density of Carabidae was significantly greater in conventionally managed compared to no-tillage or organically managed plots (Menalled et al. 2006). However, Carabidae communities captured in no-tillage plots were composed of significantly more weed-seed predators compared to the organic or conventional plots. It is possible that within the taxa sampled here, functional groups responded conversely to differing crop diversity within annual rotation.

Incorporating more crop diversity within annual rotations alone may not affect beneficial taxa. Increased planting of monocultures that are associated with annual rotation typically results in the loss of natural habitat for beneficial arthropods (Altieri and Letourneau 1982). Planting perennial crops or non-crops within agroecosystems can provide much needed habitat for beneficial arthropods (Altieri and Letourneau 1982, Altieri 1999, Landis et al. 2000) and greater vegetational diversity within agroecosystems can offer natural enemies better alternate food resources, favorable microclimates, and refuge from environmental or anthropogenic disturbances (Marion and Landis 1996, Landis et al. 2000, Sunderland and Samu 2000, Symondson et al. 2002, Gardiner et al. 2009). For example, natural enemies overwinter more often in field margins because they provide better overwintering shelter than bare crop fields (Thomas et al. 1992a). Strips of perennial grasses planted throughout agricultural fields (beetle banks) have been shown to increase the availability of stable habitats for predators and increase predator movement throughout fields (Thomas et al. 1992b). Opiliones and Lycosidae are both generalist predators (Triplehorn and Johnson 2005, Foelix 2011), yet neither taxa responded to increased crop diversity within annual rotations (Table 3). Increasing landscape heterogeneity within agroecosystems with perennial crops or non-crops increases the effectiveness of natural enemies, and incorporating more crop diversity within crop rotations can support and stabilize natural-enemy communities (Rusch et al. 2013).

Increasing diversity in rotation schemes can benefit farmers by increase crop yields and reducing reliance on chemical inputs (Bullock 1992, Smith et al. 2008, Davis et al. 2012). Results presented here indicated that activity-density of ground-dwelling beneficial communities in corn and soybean plots were not affected by altering the number of crops within annual rotation schemes (Tables 2 and 3), however diversity of beneficial arthropods was highest in corn plots that lacked rotation. Although response of beneficial taxa to crop rotation diversity varies, combining greater crop diversity within rotation schemes with perennial crops or non-crops may lead to more sustainable and robust natural enemy communities.

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Tables

Table 1. Beneficial taxa captured by pitfall traps from corn and soybean plots

			Total Capture (%)	
Class	**Order**	**Family**	**Corn**	**Soybean**
Diplopoda			113 (3%)	73 (3%)
Arachnida	Opiliones		262 (7%)	129 (5%)
	Araneae	Lycosidae	159 (4%)	133 (5%)
Insecta	Coleoptera	Carabidae	1,746 (45%)	843 (35%)
	Hymenoptera	Formicidae	1,056 (27%)	941 (39%)
	Orthoptera	Gryllidae	377 (10%)	288 (12%)

Table 2. Multivariate analysis of variance of total beneficial arthropods captured from corn and soybean plots

	Corn			Soybean		
	F	**df**	***P***	**F**	**df**	***P***
Rotation Scheme	0.54	2, 28	0.59	0.10	1, 17	0.75
Sampling Date	6.19	3, 93	**0.0007**	4.45	3, 58	**0.0070**
Rotation*Date	0.32	6, 93	0.92	0.58	3, 58	0.63

Table 3. Analysis of variance of total beneficial arthropods and individual taxa captured from corn and soybean plots

Crop	Rotation Scheme			Sampling Date			Rotation * Sampling Date		
Taxa	F	df	*P*	F	df	*P*	F	df	*P*
Corn									
Total	0.83	2, 28	0.44	6.64	3, 93	**0.0004**	0.35	6, 93	0.91
Carabidae	2.96	2, 28	0.07	3.11	3, 93	**0.030**	0.77	6, 93	0.60
Formicidae	2.10	2, 28	0.32	11.83	3, 93	**<0.0001**	0.34	6, 93	0.91
Gryllidae	0.73	2, 28	0.49	3.59	3, 93	**0.017**	0.57	6, 93	0.75
Opiliones	0.13	2, 28	0.87	0.31	3, 93	0.82	0.24	6, 93	0.96
Lycosidae	0.78	2, 28	0.47	10.74	3, 93	**<0.0001**	0.55	6, 93	0.77
Diplopoda	0.60	2, 28	0.56	6.80	3, 93	**0.0003**	0.67	6, 93	0.67
Soybean									
Total	0.04	1, 17	0.85	6.08	3, 58	**0.001**	0.12	3, 58	0.95
Carabidae	0.01	1, 17	0.94	2.15	3, 58	0.10	0.13	3, 58	0.94
Formicidae	0.02	1, 17	0.90	8.04	3, 58	**0.0001**	0.57	3, 58	0.64
Gryllidae	0.01	1, 17	0.98	3.23	3, 58	**0.029**	1.07	3, 58	0.37
Opiliones	0.11	1, 17	0.74	4.30	3, 58	**0.008**	0.09	3, 58	0.96
Lycosidae	0.26	1, 17	0.62	4.57	3, 58	**0.006**	0.65	3, 58	0.58
Diplopoda	0.27	1, 17	0.61	5.86	3, 58	**0.001**	0.37	3, 58	0.78

Table 4. Mean activity-density of the total beneficial arthropod community and individual taxa per plot by rotation scheme from corn and soybean plots

Crop Taxa	Rotation Scheme (Mean ± SEM) Continuous	 Two-Year	 Three-Year
Corn			
Total	25.4 ± 3.5	30.2 ± 4.6	25.0 ± 5.0
Carabidae	13.0 ± 2.5	14.0 ± 3.8	11.0 ± 3.9
Formicidae	5.6 ± 1.7	9.2 ± 2.2	8.1 ± 1.8
Gryllidae	3.2 ± 0.8	3.0 ± 0.7	2.0 ± 0.4
Opiliones	1.8 ± 0.3	2.3 ± 0.5	1.6 ± 0.3
Lycosidae	1.0 ± 0.2	1.2 ± 0.2	1.2 ± 0.3
Diplopoda	0.6 ± 0.1	0.8 ± 0.2	1.1 ± 0.3
Soybean			
Total	.	26.2 ± 4.9	28.5 ± 5.5
Carabidae	.	9.2 ± 2.5	10.0 ± 3.1
Formicidae	.	10.3 ± 3.8	11.1 ± 4.1
Gryllidae	.	3.1 ± 0.6	3.5 ± 0.7
Opiliones	.	1.5 ± 0.4	1.5 ± 0.4
Lycosidae	.	1.4 ± 0.3	1.6 ± 0.5
Diplopoda	.	0.7 ± 0.2	1.0 ± 0.3

Table 5. Vector coefficient of determinations for individual taxa within NMDS ordinations by crop

Crop	Vectors[a]	
Taxa	r^2	*P*
Corn		
Carabidae	0.30	0.001
Formicidae	0.30	0.001
Gryllidae	0.41	0.001
Opiliones	0.23	0.001
Lycosidae	0.06	0.014
Diplopoda	0.13	0.001
Soybean		
Carabidae	0.50	0.001
Formicidae	0.45	0.001
Gryllidae	0.54	0.001
Opiliones	0.30	0.001
Lycosidae	0.07	0.036
Diplopoda	0.07	0.031

[a] Vector statistical significance based on 999 random permutations of the data

Table 6. Mean (± SEM) Simpson's (*D*) and Simpson's evenness ($E_{1/D}$) indices by rotation scheme and sampling date from corn and soybean plots

Crop	Rotation Scheme	Sampling Date	***D*[1]**	**$E_{1/D}$[2]**
Corn	Continuous Corn		2.44 ± 0.14 a[3]	0.67 ± 0.03
	Two-Year Annual Rotation		1.93 ± 0.12 b	0.63 ± 0.03
	Three-Year Annual Rotation		2.24 ± 0.11ab	0.65 ± 0.03
		June	2.15 ± 0.12ab	0.61 ± 0.04
		July	1.93 ± 0.10 b	0.62 ± 0.04
		August	2.11 ± 0.14 b	0.70 ± 0.04
		September	2.61 ± 0.18 a	0.66 ± 0.03
Soybean	Two-Year Annual Rotation		2.24 ± 0.11	0.65 ± 0.03
	Three-Year Annual Rotation		2.17 ± 0.12	0.66 ± 0.04
		June	2.00 ± 0.13ab	0.64 ± 0.05
		July	1.94 ± 0.11 b	0.58 ± 0.04
		August	2.30 ± 0.18ab	0.69 ± 0.05
		September	2.51 ± 0.18 a	0.70 ± 0.05

[1] Simpson's index (*D*) was calculated as $D = 1 / (\sum p_i^2)$ where p_i is the proportion of individuals of species *i* among the total individuals collected. Diversity increases with increasing vales of *D*.

[2] Simpson's evenness index ($E_{1/D}$) was calculated as $E_{1/D} = (1/D) / S$ where *S* is the number of taxa collected. Measurement of $E_{1/D}$ range from 0 to 1, and values increases with decreasing species dominance.

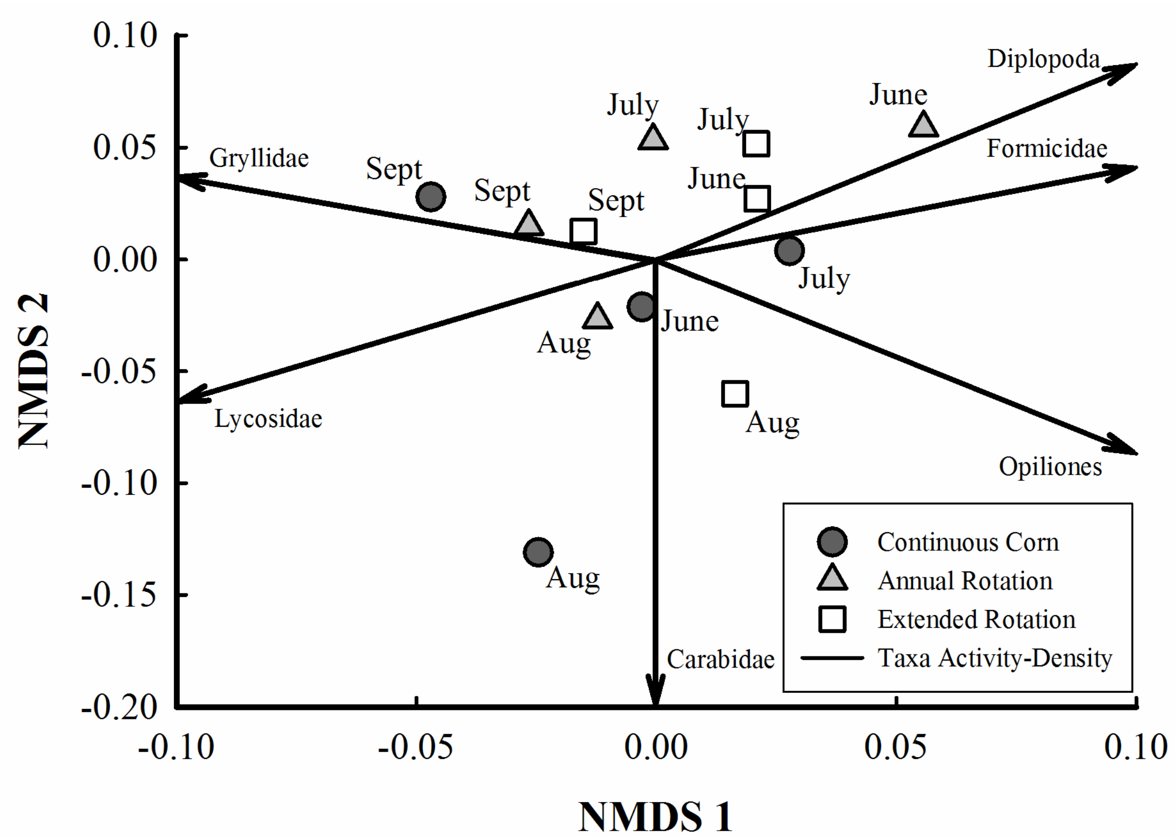
3 Letters denote significant differences either among rotation schemes or sampling date.

Figures

Figure 1. (A) Nonmetric multidimensional scaling (NMDS) ordination of beneficial arthropod community composition as captured by pitfall traps in corn plots. Centroid points represent mean community composition for each rotation scheme by sampling date combination and vectors describe changes in activity-density of individual taxa. (B) Mean activity-density of total beneficial arthropods and individual taxa as captured by pitfall traps from corn plots by sampling date. Bar height represents sample means and error bars are the standard error of the mean. Within total beneficial arthropods and each individual taxon, letters denote significant differences and 'ns' above June sampling date bars denotes no significant differences in activity-density among sampling dates.

Figure 2. (A) Nonmetric multidimensional scaling (NMDS) ordination of beneficial arthropod community composition as captured by pitfall traps in soybean plots. Centroid points represent mean community composition for each rotation scheme by sampling date combination and vectors describe changes in activity-density of individual taxa. (B) Mean activity-density of total beneficial arthropods and individual taxa as captured by pitfall traps from soybean plots by sampling date. Bar height represents sample means and error bars are the standard error of the mean. Within total beneficial arthropods and each individual taxon, letters denote significant differences and 'ns' above June sampling date bars denotes no significant differences in activity-density among sampling dates.

Figure 1A.



0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
NMDS 2
-0.10
-0.05
0.00
0.05
0.10
NMDS 1
Diplopoda
Formicidae
Gryllidae
Lycosidae
Opiliones
Carabidae
June
July
July
Sept
Sept
Sept
June
July
June
Aug
Aug
Aug
Continuous Corn
Annual Rotation
Extended Rotation
Taxa Activity-Density

Figure 1B.

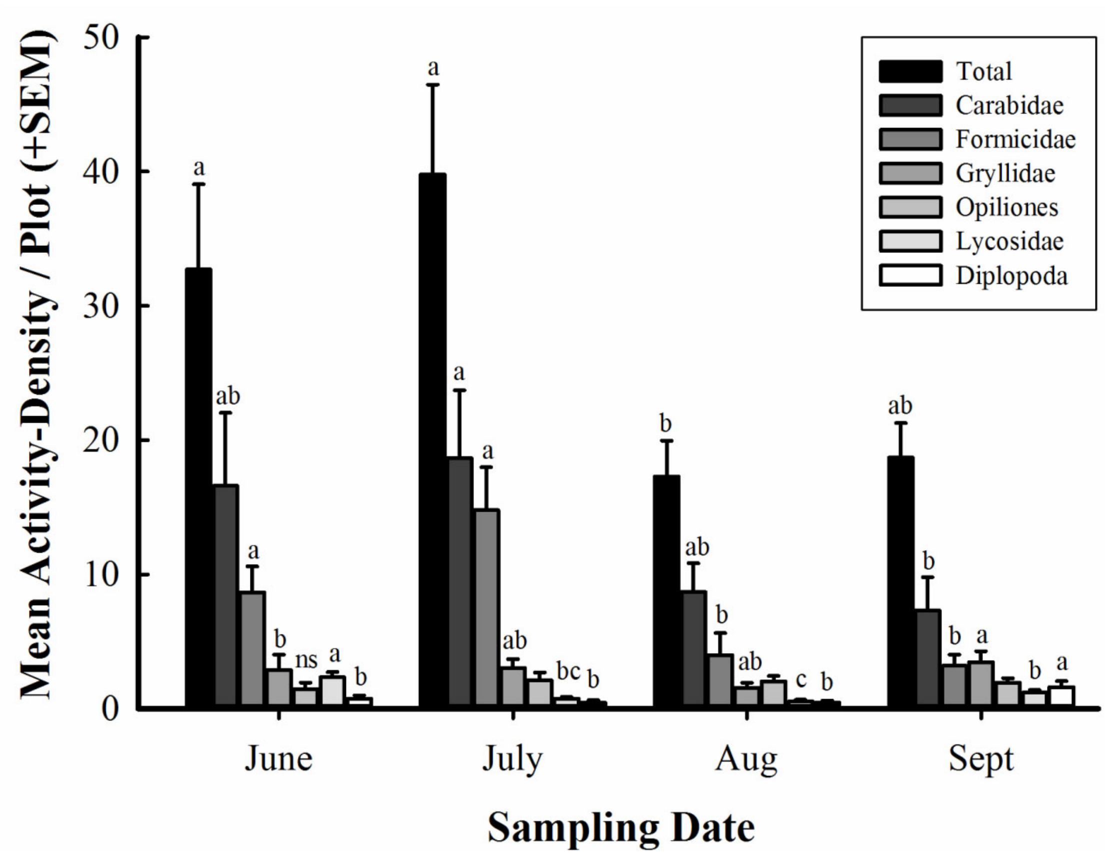
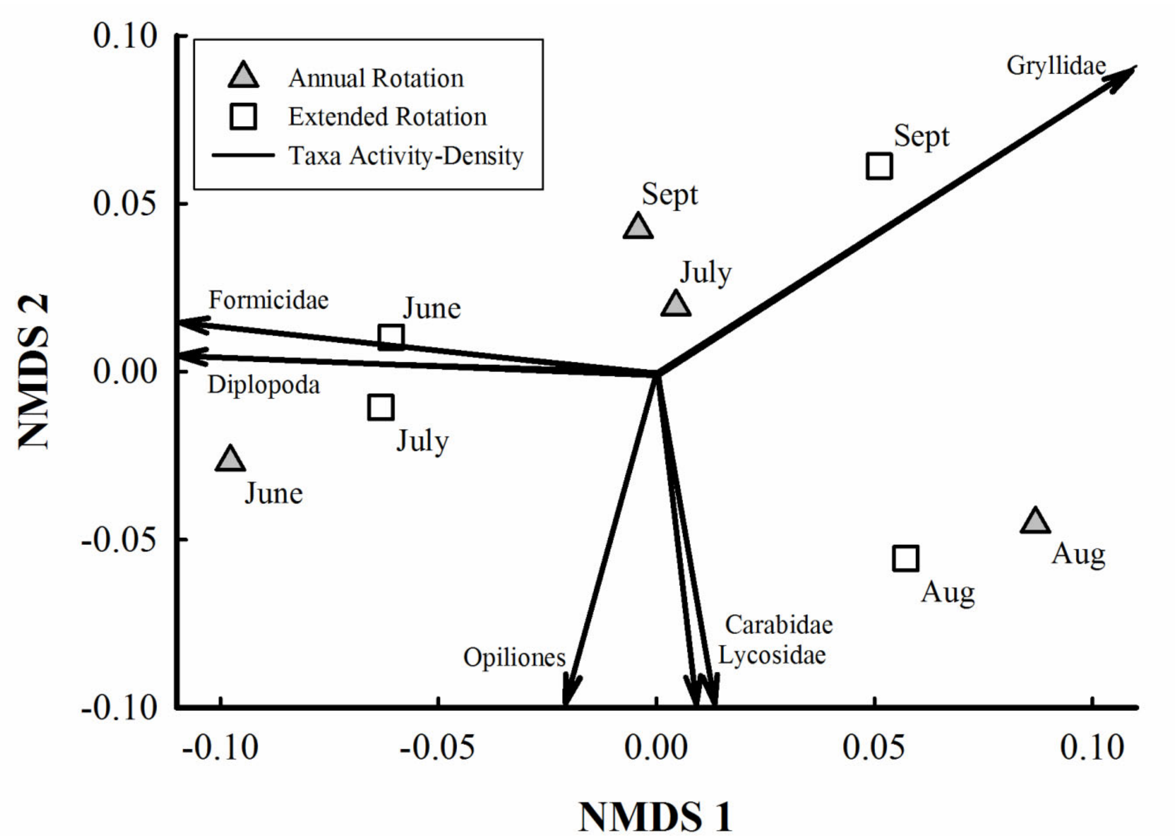
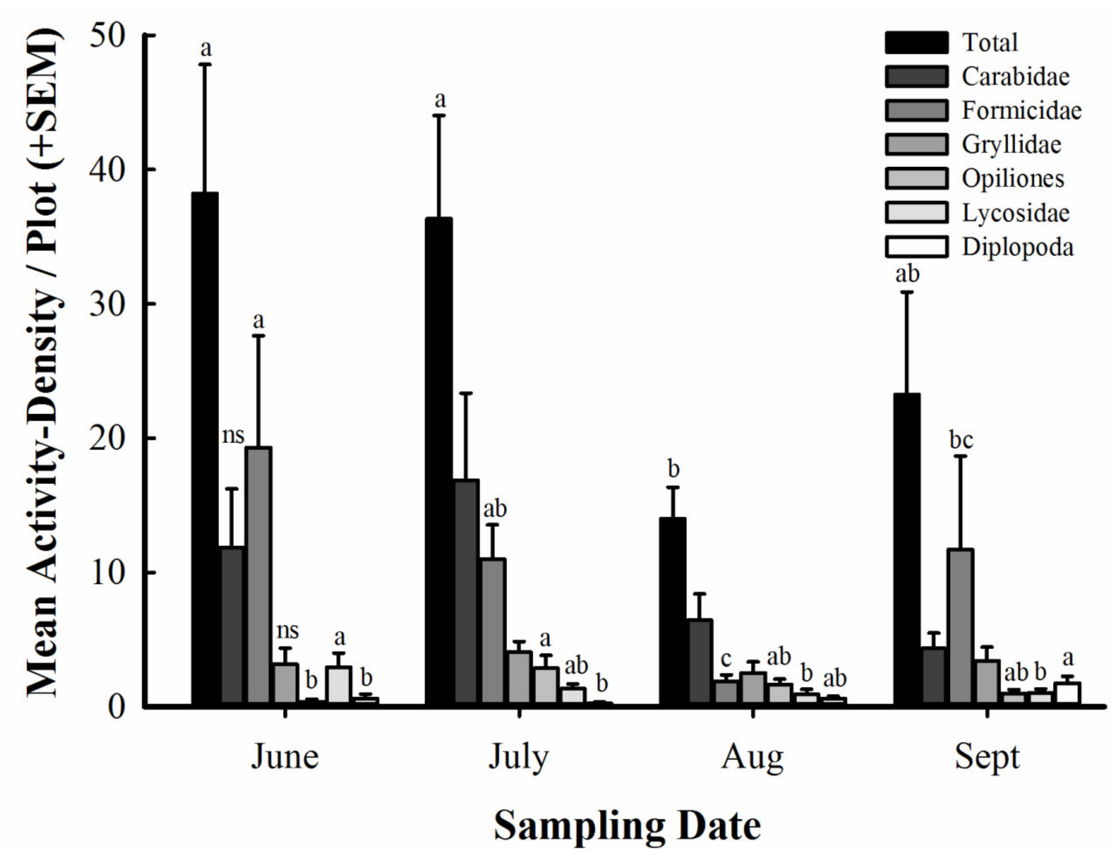

Mean Activity-Density / Plot (+SEM)
50
40
30
20
10
0
Total
Carabidae
Formicidae
Gryllidae
Opiliones
Lycosidae
Diplopoda
June
July
Aug
Sept
Sampling Date

Figure 2A.



Annual Rotation
Extended Rotation
Taxa Activity-Density
Gryllidae
Sept
Sept
July
Formicidae
June
Diplopoda
July
June
Aug
Aug
Carabidae
Lycosidae
Opiliones
0.10
0.05
0.00
-0.05
-0.10
-0.10
-0.05
0.00
0.05
0.10
NMDS 2
NMDS 1

Figure 2B.


Mean Activity-Density / Plot (+SEM)
50
40
30
20
10
0
Total
Carabidae
Formicidae
Gryllidae
Opiliones
Lycosidae
Diplopoda
a
ns
a
ns
b
a
b
a
ab
a
ab
b
b
c
ab
b
ab
ab
bc
ab
b
a
June
July
Aug
Sept
Sampling Date