4-2017

Limited Impact of a Fall-Seeded, Spring-Terminated Rye Cover Crop on Beneficial Arthropods

Mike W. Dunbar
Iowa State University

Aaron J. Gassmann
Iowa State University, aaronjg@iastate.edu

Matthew E. O'Neal
Iowa State University, oneal@iastate.edu

Limited Impact of a Fall-Seeded, Spring-Terminated Rye Cover Crop on Beneficial Arthropods

Abstract

Cover crops are beneficial to agroecosystems because they decrease soil erosion and nutrient loss while increasing within field vegetational diversity. Greater vegetational diversity within cropping systems can positively affect beneficial arthropod communities. We hypothesized that increasing the vegetational diversity within annually rotated corn and soybean with the addition of a rye cover crop would positively affect the beneficial ground and canopydwelling communities compared to rotated corn and soybean grown without a cover crop. From 2011 through 2013, arthropod communities were measured at two locations in Iowa four times throughout each growing season. Pitfall traps were used to sample ground-dwelling arthropods within corn and soybean plots and sweep nets were used to measure the beneficial arthropods in soybean canopies. Beneficial arthropods captured were identified to order and family level taxonomic units. In both corn and soybean, community composition and total community activity-density and abundance did not differ between plots that included the rye cover crop and plots without the rye cover crop. Most taxa did not significantly respond to the presence of the rye cover crop when analyzed individually, with the exceptions of Carabidae and Gryllidae sampled from soybean pitfall traps. Activity-density of Carabidae was significantly greater in soybean plots that included a rye cover crop, while activity-density of Gryllidae was significantly reduced in plots with the rye cover crop. Although a rye cover crop may be agronomically beneficial, there may be only limited effects on beneficial arthropods when added within an annual rotation of corn and soybean.

Keywords

community composition, IPM, natural enemies, Nonmetric multidimensional scaling (NMDS), pitfall traps

Disciplines

Agricultural Science | Agriculture | Entomology

Comments

This is a manuscript of an article published as Dunbar, Mike W., Aaron J. Gassmann, and Matthew E. O’Neal. "Limited impact of a fall-seeded, spring-terminated rye cover crop on beneficial arthropods." *Environmental entomology* 46, no. 2 (2017): 284-290. doi:10.1093/ee/nvw177. Posted with permission.

Limited Impact of a Fall Seeded, Spring Terminated Rye Cover Crop on Beneficial Arthropods

Mike W. Dunbar, Aaron J. Gassmann, Matthew E. O'Neal

Iowa State University, Department of Entomology, Ames, IA 50011

Abstract

Cover crops are beneficial to agroecosystems because they decrease soil erosion and nutrient loss while increasing within field vegetational diversity. Greater vegetational diversity within cropping systems can positively affect beneficial arthropod communities. We hypothesized that increasing the vegetational diversity within annually rotated corn and soybean with the addition of a rye cover crop would positively affect the beneficial ground and canopy-dwelling communities compared to rotated corn and soybean grown without a cover crop. From 2011 through 2013, arthropod communities were measured at two locations in Iowa four times throughout each growing season. Pitfall traps were used to sample ground-dwelling arthropods within corn and soybean plots and sweep nets were used to measure the beneficial arthropods in soybean canopies. Beneficial arthropods captured were identified to order and family level taxonomic units. In both corn and soybean, community composition and total community activity-density and abundance did not differ between plots that included the rye cover crop and plots without the rye cover crop. Most taxa did not significantly respond to the presence of the rye cover crop when analyzed individually, with the exceptions of Carabidae and Gryllidae sampled from soybean pitfall traps. Activity-density of Carabidae was significantly greater in soybean plots that included a rye cover crop, while activity-density of Gryllidae was significantly reduced in plots with the rye cover crop. Although a rye cover crop may be agronomically beneficial, there may be only limited effects on beneficial arthropods when added within an annual rotation of corn and soybean.

Key Words: community composition, IPM, natural enemies, Nonmetric multidimensional scaling (NMDS), pitfall traps

Introduction

Greater vegetational diversity within agroecosystems, compared to monocultures, can result in decreased pest abundance and increased abundance of beneficial arthropods i (Andow 1991a, Landis et al. 2000). Vegetational diversity can vary temporally, from crops that completely overlap in time (i.e., intercropping) to crops that are completely separated in time (i.e., traditional crop rotation schemes). Spatial diversity in agroecosystems can change at the landscape level or within fields, and even within plants. Reviews of studies that manipulated within field diversity have shown that when diversity is increased there are positive effects on beneficial arthropod abundance and negative effects on insect pest abundance (Langellotto and Denno 2004, Letourneau et al. 2011).

The addition of a cover crop increases vegetational diversity within fields (Andow 1991b). Cover crops are non-crop species planted prior to or intercropped with a cash crop (Andow 1991b, Hartwig and Ammon 2002). The benefits of adding a cover crop include reducing soil and nutrient loss as well as suppressing weeds (USDA, NRCS 2013). Rye (*Secale cereale* L.) has been recommended as a cover crop in the U.S. Corn Belt because of its cold tolerance and rapid growth early in the spring (Stoskopf 1985, Bollero and Bullock 1994, Dinnes et al. 2002). A rye cover crop in the Corn Belt is typically seeded in the fall and terminated in the spring before the cash crop is planted (Clark 2007, Casey 2012).

Cover crops may decrease insect pest abundance by creating habitat for beneficial arthropods such as natural enemies (Carmona and Landis 1999, Landis et al. 2000). Vegetation within fields can affect natural enemies by altering their mobility, the abundance of alternate prey or hosts, and the availability of favorable microclimates (Sunderland and Samu 2000, Symondson et al. 2002). European corn borer (*Ostrinia nubilalis* Hübner [Lepidoptera:

Crambidae]) used as sentinel prey in corn (*Zea mays* L.) and soybean (*Gylcine max* L.) plots were consumed at greater frequency in plots planted with an alfalfa (*Medicago sativa* L.) and kura clover (*Trifolium ambiguum* M. Bieb.) living-mulch cover crop (a type of cover crop that is grown concurrently with a cash crop) than without a cover crop (Prasifka et al. 2006). Foliar predators in soybean plots were both significantly more abundant and diverse in soybean canopies when plots also included a living-mulch cover crop of alfalfa (Schmidt et al. 2007). Furthermore, soybean aphid (*Aphis glycines* Matsumura [Hempitera: Aphididae]) population growth rates were lower in soybean plots with the living-mulch cover crop. Reduction in pest insect abundances also have been observed when rye was included as a cover crop, however the effect of rye on natural enemy abundance has been inconsistent (Bottenberg et al. 1997, Tillman et al. 2004, Koch et al. 2012). Furthermore, rye cover crop management can alter the responses of both pests and beneficial arthropods (Smith et al. 1988, Laub and Luna 1991, 1992).

The goals of this study were to quantify the effects a fall-seeded, spring-terminated rye cover crop within annually rotated corn and soybean on the composition and abundance of both ground and canopy-dwelling beneficial arthropods. We hypothesized that increasing the vegetational diversity within annually rotated corn and soybean with the addition of a rye cover crop would positively affect the beneficial arthropod community and individual taxa. To test this hypothesis, pitfall traps and sweep nets were used over a three-year period to measure beneficial arthropod communities found within plots of annually rotated corn and soybean grown with and without a rye cover crop.

Material and Methods

Experimental Design and Field Sites. Data were collected at two locations per year during 2011, 2012, and 2013 in Iowa; the Agricultural Drainage Water Research Site (ADW; Gilmore City, Pocahontas County, Iowa, 42˚74′77″ N, 94˚49′52″ W) and the Iowa State University Agronomy and Agricultural Engineering Research Farm (ISUAG, Boone, Boone County, Iowa, 42˚00′94″ N, 93˚78′06″ W). Both ADW and ISUAG have grown corn and soybean in a rotation since the 1900's (Daigh et al. 2014). At each location, no-tillage corn and soybean were rotated annually in replicated plots of 15 m × 38 m and 15 m × 6 m for ADW and ISUAG, respectively. Beginning in 2008 at ISUAG and 2010 at ADW, a rye cover crop was added into the corn-soybean rotation (Daigh et al. 2014). Rye seed was drilled (100 and 63 kg ha^{-1} for ADW and ISUAG, respectively) into a subset of randomly selected plots in the fall following the harvest of the cash crop. Rye was terminated in the spring approximately two weeks before planting of either corn or soybean using herbicide (glyphosate) and left as mulch within each plot. At each location, both corn and soybean were grown with and without a cover crop, with each combination replicated twice in a randomized complete block design.

Arthropod Sampling. During each year and at both locations, four plots of corn and soybean grown with and without a rye cover crop were sampled, for a total of 16 plots per location. Each plot was sampled for epigeal and canopy beneficial arthropods. In 2011, ADW was sampled on 21 June, 19 July, 4 August, and 4 September and ISUAG was sampled on 29 June, 19 July, 5 August, and 4 September. During 2012, both locations were sampled on the same days; 25 June, 16 July, 6 August, and 1 September. Similarly, during 2013, both locations were sampled on the same days; 20 June, 15 July, 9 August, and 7 September.

Pitfall traps were used to estimate the activity-density of epigeal arthropods. Three pitfall traps were placed within each plot, and consisted of 1 L cups (Reynolds Food Packaging, Shepherdsville, Kentucky) buried in the ground flush with the soil surface. A cover, raised ca. 5 cm above the soil surface, was used to prevent debris from entering pitfall traps (Hummel et al. 2012). To prevent arthropods from escaping traps, the bottom of each pitfall container was filled with ca. 100 mL of non-scented, soapy water solution. Pitfall traps remained in plots for 24 h during each sampling period. After 24 h, contents of pitfall traps were placed separately into sealable plastic bags and stored in freezers until contents were sorted.

Sweep nets were used to sample beneficial arthropods in soybean canopies. A sample consisted of 15 continuous pendulum sweeps of the upper soybean canopy. Sweeping locations within plots were arbitrarily chosen, but were never sampled along border rows of plots. One sweep net sample was collected per plot. Sweep net sample contents were separately placed in sealable plastic bags and stored in freezers until contents were sorted.

Insects captured in pitfall traps were identified to family, and non-insect arthropods were identified to class or order depending on the taxa. Lycosidae were separated from other Araneae individuals as Lycosidae represented 98% and 97.8% of all Araneae captured by pitfall traps in corn and soybean, respectively. Insects captured by sweeps nets were identified to family or superfamily, and non-insect arthropods were identified to order.

Statistical Analysis. For all analyses, pitfall trap and sweep net data were analyzed separately. Furthermore, pitfall trap data were analyzed separately by crop. Taxa were only included in analyses if they composed > 5% of total number of individuals captured (Costamagna and Landis 2006). Nonmetric multidimensional scaling (NMDS), multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA) were used to compare differences in beneficial arthropod community composition and to compare individual taxa by cover treatment (rye cover crop present or absent), sampling date, and their interaction.

To compare the composition of beneficial arthropod communities, NMDS analyses using Sorensen (Bray-Curtis) distances (Krebs 1999) were performed in R 3.1 statistical software (Dixon 2003, Oksanen 2013, R Core Team 2014). The NMDS summarizes the relationships among all variables and displays the relationships in ordination space. The composition of beneficial arthropod communities, represented by points within the ordination, becomes increasingly similar in composition as distances among points within the NMDS decreases. Function metaMDS in R was used to create NMDS ordination plots. Stress (*S*) and ordination non-metric fit (r^2), statistics measuring goodness of fit between the ordination distances and the data dissimilarity, were also computed (Oksanen 2013). The function envit in R was used to create centroids of mean community composition and vectors describing changes in taxa activity-density or abundance (Oksanen 2013). Centroids created represented the mean community composition for each cover treatment by sampling date combination. The vector direction within an ordination indicates the direction of most rapid increase of a taxa's activity-density or abundance. The significance of each vector's relationship to the ordination were calculated from 999 random permutations of these data (Oksanen 2013). Vectors were displayed only if they had a significant relationship with the ordination.

Activity-density and abundance of taxa were analyzed with repeated-measures MANOVA, based on a split-plot design (Quinn and Keough 2002), that included the factors of cover treatment, sampling date and their interaction in SAS statistical software version 9.3 (PROC GLM) (SAS Institute, Cary, North Carolina). Data were log (x + 0.5) function transformed to increase the normality of the residuals. Fixed model effects were cover treatment, sampling date and the interaction of cover treatment and sampling date. Random effects included year, location, the interaction of year and location, plot nested within the interaction of year × location × cover treatment and sampling date × plot nested within year × location × cover treatment. The inclusion of the sampling date × plot nested within year × location × cover treatment term in the model makes this a repeated-measures design.

Total capture and capture of each individual taxa were analyzed using repeated measures ANOVA (PROC MIXED) in SAS 9.3. Total captured was measured as the activity-density or abundance of all individuals captured by pitfall traps or sweep nets. To meet the assumptions of the ANOVA, data were transformed by the log $(x + 0.5)$ function. Cover treatment, sampling date, and their interactions were classified as fixed effects. Random effects were year, location, the interaction of year and location, plot nested within the interaction of year × location × cover treatment and sampling date × plot nested within year × location × cover treatment. When significant effects were present ($P < 0.05$), pairwise comparisons were made using the PDIFF option (in PROC MIXED). Alpha levels were adjusted for multiple comparisons using the Bonferroni correction.

Results

Pitfall traps in corn plots captured over 2,200 individual beneficial arthropods, representing ten different taxa. Six of those taxa individually represented > 5% of the total community and were included in all analyses (Table 1). Epigeal taxa from corn plots excluded were Isopoda, Chilopoda, Araneae (non-Lycosidae taxa), and Staphylinidae (Coleoptera). More than 2,600 beneficial arthropods representing ten different taxa were captured by pitfall traps in soybeans plots, and five taxa each composing > 5% of the total capture were included in analyses (Table 1). Excluded taxa included Isopoda, Chilopoda, Opiliones (Arachnida), Araneae (non-Lycosidae taxa), and Staphylinidae (Coleoptera). Thirteen different beneficial taxa were captured by sweep net sampling of soybean canopies. Eight taxa were captured in abundances > 5% of the total number of individuals captured (Table 1). The remaining taxa that were excluded from sweep net community analyses were Reduviidae (Hemiptera), Braconidae (Hymenoptera), Ichneumonidae (Hymenoptera), Asilidae (Diptera), and Dolichopodidae (Diptera).

Analysis by NMDS reached solutions with low stress for pitfall trap data from corn (S = 0.09; Fig. 1), pitfall trap data from soybean (S = 0.07; Fig. 2) and sweep net data from soybeans (S = 0.11; Fig. 3). Additionally, NMDS ordination distances correlated with corn and soybean pitfall trap and soybean sweep net data dissimilarity (non-metric fit r^2 = 0.992, 0.995, and 0.988, respectively). The rye cover crop did not significantly affect total beneficial arthropod composition in any of the three communities sampled as tested by MANOVA (Table 2). However, epigeal and canopy community compositions from both corn and soybean were significantly affected by sampling date (Table 2).

Overall epigeal activity-density did not differ by cover treatment in either corn or soybean plots (Tables 3 and 4). Analysis of overall epigeal activity-density in soybean plots showed that sampling date did have a significant effect (Tables 3 and 4), however there were no significant pairwise comparisons among sampling dates after adjusting alpha levels for multiple comparisons. In soybean canopies, total beneficial abundance was significantly affected by sampling date (Table 3), with total abundance as capture by sweep netting the lowest during June (Table 4).

When taxa were analyzed individually by ANOVA, Carabidae and Gryllidae captured from soybean plots were the only taxa significantly affected by the cover treatment (Table 4; Supp. Table S1). Activity-density of Carabidae was significantly greater in soybean plots that included the rye cover crop. Gryllidae responded conversely; activity-density was significantly greater in soybean plots without a cover crop. The majority of taxa were affected by sampling date, with Syrphidae and Tachinidae captured from soybean canopies the only two exceptions (Table 4; Supp. Table S1).

Vectors describing changes in activity-density or abundance of individual taxa were significantly correlated to the NMDS ordinations for the majority of taxa, with the exceptions of Diplopoda captured from both corn and soybean pitfall traps and Chalcidoidea collected from soybean canopies (Table 5). Within epigeal communities of both crops, changes in Formicidae and Gryllidae activity-density were best represented by the NMDS ordinations (Table 5; Figs. 1 and 2). In soybean canopies, dissimilarity within the NMDS best described the changes in Coccinellidae abundance (Table 5; Fig. 3).

Discussion

The objective of this study was to quantify the effects of a rye cover crop planted within annually rotated corn and soybean on both the beneficial ground and canopy-dwelling communities. Community compositions and most individual taxa did not respond significantly to the addition of the rye cover crop (Tables 2, 3, and 4). Community compositions were more often affected by sampling date (Table 2 and 3), as capture of nearly all individual taxa significantly varied by sampling date (Table 4; Supp. Table S1). Of those taxa that did respond to the addition of the rye cover crop, Carabidae were more frequently captured during June and July sampling dates while Gryllidae were least frequently captured during June sampling (Table 4). Similar temporal patterns have been observed in other studies conducted in the Corn Belt for both Carabidae (O'Rourke et al. 2008) and Gryllidae (Carmona et al. 1999).

The enemies hypothesis predicts that natural enemies such as predators and parasitoids would be more abundant in agroecosystems with greater vegetational diversity compared to monocultures (Root 1973, Andow 1991a). However, Carabidae captured from soybean plots were the only individual taxa in the entire study to have significantly greater activity-density when rye was included within the rotation (Table 4). Carabidae are a diverse group with a wide range of life-history traits (Kromp 1999), and Carabidae response to field-level management can vary by practice, such as tillage (Brust et al. 1986, Menalled et al. 2006) or organic farming (Garratt et al. 2011). For example, Menalled et al. (2006) found significantly greater activity-density of Carabidae in conventionally tilled plots compared to no till plots, yet the percentage of weed-seed predator species increased from 4% of individuals in the conventionally tilled plots to 32% of individuals in the no tillage plots. Another common natural enemy is Araneae, which has been observed to respond strongly to increased diversification within fields (Sunderland and Samu 2000, Langellotto and Denno 2004). Surprisingly, there was no significant effect of rye cover crop on activity-density of Lycosidae in either corn or soybean or on the abundance of Araneae in soybean canopies (Table 4).

Natural enemies in soybean canopies primarily consist of predators (Rutledge et al. 2004, Schmidt et al. 2008). Although foliar predators in soybean do respond positively to some living-mulch cover crops (Schmidt et al. 2007), we observed no effect of a fall-seeded, spring-terminated rye cover crop on the abundance any individual predator taxa in soybean canopies

(Table 4). Other studies have reported similar results. Foliar predator abundance did not differ between small plots of organic soybean planted with and without a rye cover crop (Koch et al. 2012), and a similar on-farm study found predators in organic soybean responded more to prey abundance rather than the presence or absence of rye cover crop (Koch et al. 2015). The addition of a rye cover crop into snap beans (*Phaseolus vulgaris* L.) also had no effect on foliar predators, and when rye was combined with another cover crop, red clover (*Trifolium pretense* L.), abundance of the predacious insidious flower bug (*Orius insidiosus* Say [Hempitera: Anthocoridae]) was reduced (Bottenberg et al. 1997). Parasitoid taxa, Chalcidoidae and Tachinidae, represented a fifth of all beneficial arthropods captured from soybean canopies (Table 1). We anticipated that parasitoid abundance would increase in fields with greater vegetational diversity, as predicted by the enemies hypothesis, and in some studies, greater habitat complexity has been shown to positively affect parasitoid abundance (Langellotto and Denno 2004). However, we found no evidence that the rye cover crop increased parasitoid abundance, as neither parasitoid taxa different in abundance between plots with or without the rye cover crop (Table 4).

How rye cover crop is managed within fields could further complicate predator and pest interactions. The recommended time that a rye cover crop should be terminated is two to three weeks before the cash crop is planted in order to prevent the rye from negatively affecting the cash crop (Tollenaar et al. 1993, Casey 2012, MCCC 2012). Rye termination can be achieved by mechanical processes (i.e., mowing, crimping, or tillage) or terminated chemically with herbicide (Clark 2007, Casey 2012). A study measuring the effect of rye termination practices on parasitoid and predator activity in corn found that early-season activity-densities of Lycosidae and Carabidae peaked earlier in the year when rye was destroyed by mowing compared to destruction with an herbicide (Laub and Luna 1992). Lycosidae and Carabidae both had significantly greater activity-density earlier in the season when sampled in corn, but we did not observe a significant interaction between sampling date and cover treatment for either taxa (Supp. Table S1). Also absent was as significant sampling date and cover treatment interaction for Carabidae sampled from soybean plots, although Carabidae did respond positively to the addition of a rye cover crop in soybean (Table 4; Supp. Table S1). Why Carabidae responded to the rye cover crop in soybean plots but not in corn is unclear. One possibility could that because soybean in the Corn Belt is often planted later in the spring compared to corn, and the rye cover crop within in soybean plots was terminated at later dates and provided favorable habitat further into spring.

Activity-density of Gryllidae in soybean plots was significantly reduced in the rye cover crop treatment (Table 4). Beneficial arthropods such as granivores, including Gryllidae, Carabidae, and Formicidae, significantly contribute to weed suppression (Menalled et al. 2006, Westerman et al. 2008, Baraibar et al. 2009), and cover crops can positively affect the activity-density of weed seed predators (Ward et al. 2011). Why Gryllidae was captured more frequently in plots without the rye cover crop is unclear. Reduced activity-density could be due in part to the residue from the terminated rye cover crop restricting the movement of Gryllidae or reducing their need to forage. Another hypothesis could be that suppression of weeds over time by the rye cover crop may have decreased the availability of food resources for Gryllidae. The growth of weed seedbanks are positively related to weed biomass (Teasdale et al. 2003), and the addition of a rye cover crop has been shown to both reduce weed biomass (Moyer et al. 2000, Weston and Duke 2003) and weed seedbank density (Moonen and Barberi 2004). However, neither the weed biomass nor weed seedbank density were measured during this study.

Cover crops can benefit corn and soybean farmers by reducing the loss of soil and nutrients (Hartwig and Ammon 2002) and suppressing weed and insect pests (Weston and Duke 2003, Koch et al. 2012). The results of this study suggest that adding a fall-seeded, spring-terminated rye cover crop to annual rotations of corn and soybean generally did not affect most beneficial taxa, with the exception of Carabidae and Gryllidae sampled from soybean plots. These data only partly support the enemies hypothesis that greater vegetational diversity within fields will increase abundance of natural enemies (Root 1973), as activity-density of Carabidae was significantly greater in plots that included the rye cover crop. The enemies hypothesis also predicts that the greater presence of natural enemies in diverse cropping systems would result in decreased pest pressure. As pest abundance was not measured in this study, the extent that the differences in activity-density of Carabidae observed here would reduce pest pressure or whether changes in prey availability due to the rye cover crop affected the activity-density of Carabidae both remain untested.

Acknowledgements

We would like to thank E. Saalau-Rojas, I. Alvarez-Castro, B. Brenizer, C. Brown, O. Dion, M. Manning, L. Momberg, and A. Schroder for their technical assistance. R. Hellmich, E. Hodgson, G. Munkvold, E. Saalau-Rojas, and A. Varenhorst provided comments on an earlier version of this manuscript. This research is part of a regional collaborative project supported by the USDA-NIFA, Award No. 2011-68002-30190, “Cropping Systems Coordinated Agricultural Project: Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems.” Project Web site: sustainablecorn.org.

Reference Cited

Andow, D. A. 1991a. Vegetational diversity and arthropod population response. Annu. Rev. Entomol. 36: 561-586.

Andow, D. A. 1991b. Yield loss to arthropods in vegetationally diverse agroecosystems. Environ. Entomol. 20: 1228-1235.

Baraibar, B., P. R. Westerman, E. Carrion, and J. Recasens. 2009. Effects of tillage and irrigation in cereal fields on weed seed removal by seed predators. J. Appl. Ecol. 46: 380-387.

Bollero, G. A., and D. G. Bullock. 1994. Cover cropping systems for the central Corn Belt. J. Prod. Agric. 7: 55-58.

Bottenberg, H., J. Masiunas, C. Eastman, and D. M. Eastburn. 1997. The impact of rye cover crops on weeds, insects, and diseases in snap bean cropping systems. J. Sust. Agric. 9: 131-155.

Brust, G. E., B. R. Stinner, and D. A. McCartney. 1986. Predation of soil inhabiting arthropods in intercropped and monoculture agroecosystems. Agric. Ecosyst. Environ. 18: 145-154.

Carmona, D. M., and D. L. Landis. 1999. Influence of refuge habitats and cover crops on seasonal activity-density of ground beetles (Coleoptera: Carabidae) in field crops. Environ. Entomol. 28: 1145-1153.

Carmona, D. M., F. D. Menalled, and D. A. Landis. 1999. *Gryllus pennsylvanicus* (Orthoptera: Gryllidae): laboratory weed seed predation and within field activity-density. J. Econ. Entomol. 92: 825-829.

Casey, P. A. 2012. Plant guide for cereal rye (*Secale cereale*). United States Department of Agriculture, Natural Resource Conservation Service, Plant Materials Center, Elsberry, MO.

Clark, A. 2007. Rye *Secale cereale*. *In* A. Clark (ed.) Managing Cover Crops Profitably, 3rd edition. Sustainable Agriculture Network, Beltsville, MD.

Costamagna, A. C., and D. A. Landis. 2006. Predators exert top-down control of soybean aphids across a gradient of agricultural management systems. Ecol. Appl. 16: 1619-1628.

Daigh, A. L., M. J. Helmers, E. Kladivko, X. Zhou, R. Goeken, J. Cavdini, D. Barker, and J. Sawyer. 2014. Soil water during the drought of 2012 as affected by rye cover crops in fields in Iowa and Indiana. J. Soil Water Conserv. 69: 564-573.

Dinnes, D. L., D. L. Karlen, D. B. Jaynes, T. C. Kaspar, J. L. Hatfield, T. S. Colvin, and C. A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agron. J. 94: 153-171.

Dixon, P. 2003. VEGAN, a package of R functions for community ecology. J. Vegetat. Sci. 14: 927-930.

Garratt, M. P. D., D. J. Wright, and S. R. Leather. 2011. The effects of farming systems and fertilizers on pests and natural enemies: a synthesis of current research. Agric. Ecosyst. Environ. 141: 261-270.

Hartwig, N. L., and H. U. Ammon. 2002. Cover crops and living mulches. Weed Sci. 50: 688-699.

Hummel, J. D., L. M. Dosdall, G. W. Clayton, K. N. Harker, and J. T. O'Donovan. 2012. Ground beetle (Coleoptera: Carabidae) diversity, activity density, and community structure in a diversified agroecosystem. Environ. Entomol. 41: 72-80.

Koch, R. L., P. M. Porter, M. M. Harbur, M. D. Abrahamson, K. A. G. Wyckhuys, D. W. Ragsdale, K. Buckman, Z. Sezen, and G. E. Heimpel. 2012. Response of soybean insects to an autumn-seeded rye cover crop. Env. Entomol. 41: 750-760.

Koch, R. L., Z. Sezen, P. M. Porter, D. W. Ragsdale, K. A. G. Wyckhuys, and G. E. Heimpel. 2015. On-farm evaluation of a fall-seeded rye cover crop for suppression of soybean aphid (Hemiptera: Aphididae) on soybean. Agr. Forest Entomol. 17: 239-246.

Krebs, C. J. 1999. Ecological methodology, 2nd ed. Benjamin Cummings, New York, NY.

Kromp, B. 1999. Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. Agric. Ecosyst. Environ. 74: 187-228.

Landis, D. A., S. D. Wratten, and G. M. Gurr. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu. Rev. Entomol. 45: 175-201.

Langellotto, G. A., and R. F. Denno. 2004. Responses of invertebrate natural enemies to complex-structured habitats: a meta-analytical synthesis. Oecologia. 139: 1-10.

Laub, C. A., and J. M. Luna. 1991. Influence of winter cover crop suppression practice on seasonal abundance of armyworm (Lepidoptera: Noctuidae), cover crop regrowth, and yield in no-till corn. Environ. Entomol. 20: 749-754.

Laub, C. A., and J. M. Luna. 1992. Winter cover crop suppression practices and natural enemies of armyworm (Lepidoptera: Noctuidae) in no-till corn. Environ. Entomol. 21: 41-49.

Letourneau, D. K., I. Armbrecht, B. S. Rivera, J. M. Lerma, E. J. Carmona, M. C. Daza, S. Escobar, V. Galindo, C. Gutierrez, S. D. Lopez, J. L. Mejia, A. M. A. Rangel, J. H. Rangel, L. Rivera, C. A. Saavedra, A. M. Torres, and A. R. Trujillo. 2011. Does plant diversity benefit agroecosystems? a synthetic review. Ecol. Appl. 21: 9-21.

[MCCC] Midwest Cover Crops Council. 2012. Midwest cover crops field guide. (http://www.mccc.msu.edu/)

Menalled, F. D., R. G. Smith, J. T. Dauer, and T. B. Fox. 2006. Impact of agricultural management on carabid communities and weed seed predation. Agric. Ecosyst. Environ. 118: 49-54.

Moonen, A. C., and P. Barberi. 2004. Size and composition of the weed seedbank after 7 years of different cover-crop-maize management systems. Weed Res. 44: 163-177.

Moyer, J. R., R. E. Blackshaw, E. G. Smith, and S. M. McGinn. 2000. Cereal cover crops for weed suppression in a summer fallow wheat cropping sequence. Can. J. Plant Sci. 80: 441-449.

Oksanen, J. 2013. Multivariate analysis of ecological communities in R: vegan tutorial. (http://cc.oulu.fi/~jarioksa/opetus/metodi/vegantutor.pdf)

O'Rourke, M. E., M. Liebman, and M. E. Rice. 2008. Ground beetle (Coleoptera: Carabidae) assemblages in conventional and diversified crop rotation systems. Environ. Entomol. 37: 121-130.

Prasifka, J. R., N. P. Schmidt, K. A. Kohler, M. E. O'Neal, R. L. Hellmich, and J. W. Singer. 2006. Effects of living mulches on predator abundance and sentinel prey in a corn-soybean-forage rotation. Environ. Entomol. 35: 1423-1431.

Quinn, G. P., and M. J. Keough. 2002. Experimental design and data analysis for biologists. Cambridge University Press, Cambridge, United Kingdom.

R Core Team. 2014. R: a language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. (http://www.R-project.org).

Root, R. B. 1973. Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracae*). Ecol. Monogr. 43: 95-124.

Rutledge, C. E., R. J. O'Neil, T. B. Fox, and D. A. Landis. 2004. Soybean aphid predators and their use in integrated pest management. Ann. Entomol. Soc. Am. 97: 240-248.

Schmidt, N. P., M. E. O'Neal, and J. W. Singer. 2007. Alfalfa living mulch advances biological control of soybean aphid. Environ. Entomol. 36: 416-424.

Schmidt, N. P., M. E. O'Neal, and P. M. Dixon. 2008. Aphidophagous predators in Iowa soybean: a community comparison across multiple years and sampling methods. Ann. Entomol. Soc. Am. 101: 341-350.

Smith, A. W., R. B. Hammond, and B. R. Stinner. 1988. Influence of rye-cover crop management on soybean foliage arthropods. Environ. Entomol. 17: 109-114.

Stoskopf, N. C. 1985. Rye, pp. 403-414. *In* Cereal grain crops. Reston Publishing Company, Inc., Reston, VA.

Sunderland, K., and F. Samu. 2000. Effects of agricultural diversification on the abundance, distribution, and pest control potential of spiders, a review. Entomol. Exp. Appl. 95: 1-13.

Symondson, W. O. C., K. D. Sunderland, and M. H. Greenstone. 2002. Can generalist predators be effective biocontrol agents? Annu. Rev. Entomol. 47: 561-594.

Teasdale, J. R., R. W. Mangum, J. Radhakrishnan, and M. A. Cavigelli. 2003. Factors influencing annual fluctuations of the weed seedbank at the long-term Beltsville Farming Systems Project. Asp. Appl. Biol. 69: 93-99.

Tillman, G., H. Schomberg, S. Phatak, B. Mullinix, S. Lachnicht, P. Timper, and D. Olson. 2004. Influence of cover crops on insect pests and predators in conservation tillage cotton. J. Econ. Entomol. 97: 1217-1232.

Tollenaar, M., M. Mihajlovic, and T. J. Vyn. 1993. Corn growth following cover crops: influence of cereal cultivar, cereal removal, and nitrogen rate. Agron. J. 85: 251-255.

(USDA, NRCS) United States Department of Agriculture, Natural Resource Conservation Service. 2013. Iowa agronomy technical note 38: cover crop management. USDA, Natural Resource Conservation Service. (https://prod.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1166106.pdf)

Ward, M. J., M. R. Ryan, W. S. Curran, M. E. Barbercheck, and D. A. Mortensen. 2011. Cover crops and disturbance influence activity-density of weed seed predators *Amara aenea* and *Harpalus pensylvanicus* (Coleoptera: Carabidae). Weed Sci. 59: 76-81.

Weston, L. A., and S. O. Duke. 2003. Weed and crop allelopathy. Crit. Rev. Plant. Sci. 22: 367-389.

Westerman, P. R., J. K. Borza, J. Andjelkovic, M. Liebman, and B. Danielson. 2008. Density-dependent predation of weed seeds in maize fields. J. Appl. Ecol. 45: 1,612-1,620.

Tables

Table 1. Taxa captured from corn and soybean plots by sampling method

Sample Method			**Total Capture (%)**	
Class	**Order**	**Family**	**Corn**	**Soybean**
Pitfall trap			2,292 (100%)	2,696 (100%)
Diplopoda			261 (11%)	121 (5%)
Arachnida	Opiliones		103 (5%)	.
	Araneae	Lycosidae	248 (11%)	558 (21%)
Insecta	Coleoptera	Carabidae	163 (7%)	247 (9%)
	Hymenoptera	Formicidae	415 (18%)	812 (30%)
	Orthoptera	Gryllidae	1,025 (45%)	826 (31%)
Sweep net			.	526 (100%)
Arachnida	Araneae		.	61 (12%)
Insecta	Hemiptera	Anthocoridae	.	48 (9%)
		Nabidae	.	30 (6%)
	Neuroptera	Chrysopidae	.	90 (17%)
	Coleoptera	Coccinellidae	.	85 (16%)
	Hymenoptera	Chalcidoidea	.	48 (9%)
	Diptera	Syrphidae	.	62 (12%)
		Tachinidae	.	57 (11%)

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

	Cover Treatment			Sampling Date			Trt*Date		
Sampling Method/ Crop	***F***	**df**	***P***	***F***	**df**	***P***	***F***	**df**	***P***
Pitfall trap/ Corn	0.21	1, 40	0.65	4.36	3, 135	**0.006**	1.98	3, 135	0.12
Pitfall trap/ Soybean	0.27	1, 41	0.60	6.05	3, 136	**0.0007**	2.40	3, 136	0.07
Sweep net/ Soybean	0.04	1, 41	0.84	8.24	3, 137	**<0.0001**	1.29	3, 137	0.28

Table 3. Analysis of variance of total beneficial arthropods captured from corn and soybean plots by sampling method and crop

	Cover Treatment			Sampling Date			Trt*Date		
Sampling Method / Crop	***F***	**df**	***P***	***F***	**df**	***P***	***F***	**df**	***P***
Pitfall / Corn	0.65	1, 40	0.41	2.16	3, 135	0.10	1.83	3, 135	0.14
Pitfall / Soybean	0.01	1, 41	0.99	2.79	3, 136	**0.043**[a]	1.56	3, 136	0.20
Sweep net / Soybean	0.22	1, 41	0.64	10.08	3, 137	**<0.0001**	1.67	3, 137	0.18

[a] No significant differences detected among sampling dates after adjusting alpha levels for multiple comparisons.

Table 4. Total and individual taxa captured per plot (mean ± standard error of the mean) from corn and soybean plots by sampling method and crop

Sampling Method/ Crop	Taxa	Cover Treatment[a] No Cover	Rye Cover	Sampling Date[b] June	July	August	September
Pitfall trap/ Corn	Total	12.3 ± 1.42	11.3 ± 1.39	11.43 ± 2.06	12.11 ± 1.71	8.68 ± 1.28	14.91 ± 2.59
	Diplopoda	2.02 ± 0.98	0.73 ± 0.18	0.98 ± 0.28a	0.00 ± 0.00b	0.00 ± 0.00b	4.57 ± 1.95c
	Opiliones	0.58 ± 0.15	0.51 ± 0.12	0.17 ± 0.08a	0.26 ± 0.08a	0.53 ± 0.16ab	1.23 ± 0.31b
	Lycosidae	1.13 ± 0.30	1.53 ± 0.61	1.53 ± 0.33a	2.96 ± 1.26a	0.30 ± 0.09b	0.49 ± 0.13b
	Carabidae	0.73 ± 0.14	1.01 ± 0.17	1.49 ± 0.33a	0.89 ± 0.17a	0.68 ± 0.16ab	0.40 ± 0.15b
	Formicidae	1.84 ± 0.50	2.59 ± 0.94	4.91 ± 1.73a	2.21 ± 0.60ab	1.45 ± 0.92bc	0.26 ± 0.13c
	Gryllidae	5.97 ± 0.75	4.91 ± 0.72	2.34 ± 0.43a	5.79 ± 0.86b	5.72 ± 0.96b	7.96 ± 1.47b
Pitfall trap/ Soybean	Total	13.3 ± 2.36	13.7 ± 2.90	17.77 ± 4.41	18.52 ± 5.50	7.89 ± 1.43	9.60 ± 1.45
	Diplopoda	0.69 ± 0.19	0.58 ± 0.16	0.79 ± 0.25b	0.06 ± 0.05c	0.02 ± 0.02c	1.68 ± 0.39a
	Lycosidae	3.23 ± 1.44	3.54 ± 2.32	1.63 ± 0.36a	8.81 ± 5.36a	0.40 ± 0.12bc	0.81 ± 0.17ac
	Carabidae	0.97 ± 0.18	1.63 ± 0.26*	2.02 ± 0.41a	1.19 ± 0.22ab	1.19 ± 0.34bc	0.79 ± 0.26c
	Formicidae	4.29 ± 1.71	4.26 ± 1.64	12.31 ± 4.26a	1.92 ± 0.45b	1.96 ± 1.29bc	0.79 ± 0.64c
	Gryllidae	5.05 ± 0.69	3.66 ± 0.50*	1.02 ± 0.18a	6.54 ± 1.13b	4.32 ± 0.57b	5.53 ± 0.98b
Sweep net/ Soybean	Total	2.40 ± 0.34	2.64 ± 0.41	0.77 ± 0.24a	2.45 ± 0.37b	3.00 ± 0.64b	3.85 ± 0.65b
	Araneae	0.38 ± 0.08	0.26 ± 0.07	0.17 ± 0.07a	0.64 ± 0.16bc	0.29 ± 0.09ac	0.19 ± 0.08a
	Anthocoridae	0.20 ± 0.07	0.31 ± 0.13	0.00 ± 0.00a	0.26 ± 0.09ab	0.23 ± 0.09a	0.52 ± 0.25b
	Nabidae	0.13 ± 0.05	0.19 ± 0.05	0.02 ± 0.02a	0.13 ± 0.07a	0.08 ± 0.05a	0.04 ± 0.10b
	Chrysopidae	0.44 ± 0.12	0.51 ± 0.11	0.00 ± 0.00a	0.38 ± 0.15ab	0.73 ± 0.20b	0.77 ± 0.19b
	Coccinellidae	0.35 ± 0.15	0.54 ± 0.22	0.06 ± 0.05a	0.09 ± 0.05a	0.29 ± 0.11ab	0.13 ± 0.50b
	Chalcidoidea	0.26 ± 0.07	0.24 ± 0.07	0.06 ± 0.04a	0.45 ± 0.11b	0.21 ± 0.10ab	0.29 ± 0.12ab
	Syrphidae	0.42 ± 0.12	0.23 ± 0.08	0.21 ± 0.14	0.30 ± 0.12	0.54 ± 0.20	0.25 ± 0.09
	Tachinidae	0.23 ± 0.07	0.37 ± 0.14	0.25 ± 0.08	0.21 ± 0.09	0.63 ± 0.28	0.10 ± 0.04

[a] Significant difference in activity-density between cover treatments, denoted with '*'.

[b] Letters denotes significant differences in activity-density among sampling dates.

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

		Vectors[a]			
		Corn		Soybean	
Sampling Method	**Taxa**	r^2	P	r^2	P
Pitfall trap					
	Diplopoda	0.02	0.24[b]	0.03	0.07
	Opiliones	0.10	0.001	.	.
	Lycosidae	0.08	0.003	0.20	0.001
	Carabidae	0.27	0.001	0.07	0.001
	Formicidae	0.64	0.001	0.56	0.001
	Gryllidae	0.59	0.001	0.46	0.001
Sweep net					
	Araneae	.	.	0.29	0.001
	Anthocoridae	.	.	0.35	0.001
	Nabidae	.	.	0.08	0.003
	Chrysopidae	.	.	0.20	0.001
	Coccinellidae	.	.	0.71	0.001
	Chalcidoidea	.	.	0.04	0.051
	Syrphidae	.	.	0.36	0.001
	Tachinidae	.	.	0.14	0.006

[a] Vector statistical significance based on 999 random permutations of the data
[b] Non-significant vectors are not displayed in NMDS figures

Figure Legends

Figure 1. Nonmetric multidimensional scaling (NMDS) of beneficial arthropod community composition as captured by pitfall traps in corn plots. Centroid points represent mean community composition for each cover treatment by sampling date combination.

Figure 2. Nonmetric multidimensional scaling (NMDS) of beneficial arthropod community composition as captured by pitfall traps in soybean plots. Centroid points represent mean community composition for each cover treatment by sampling date combination.

Figure 3. Nonmetric multidimensional scaling (NMDS) of beneficial arthropod community composition as captured by sweep net sampling in soybean plots. Centroid points represent mean community composition for each cover treatment by sampling date combination.

Figures

Figure 1.

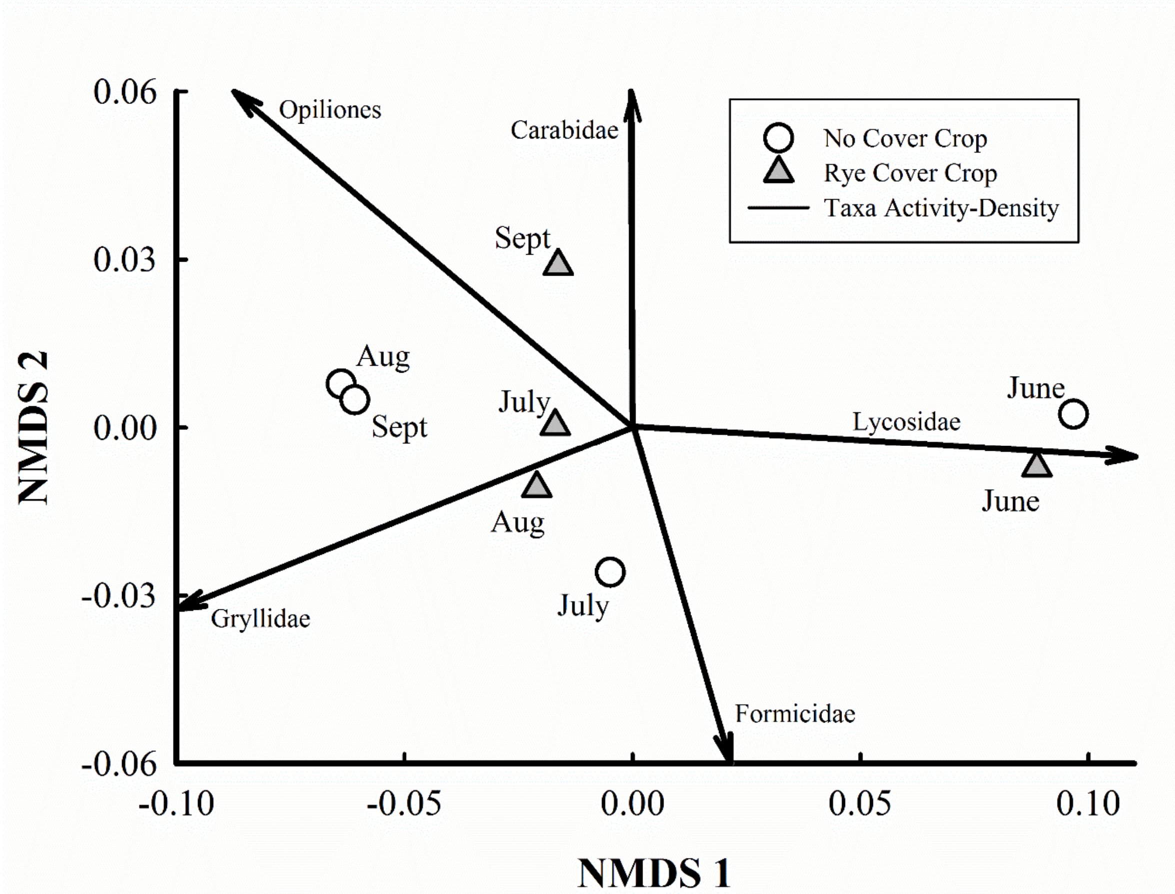


Figure 2.

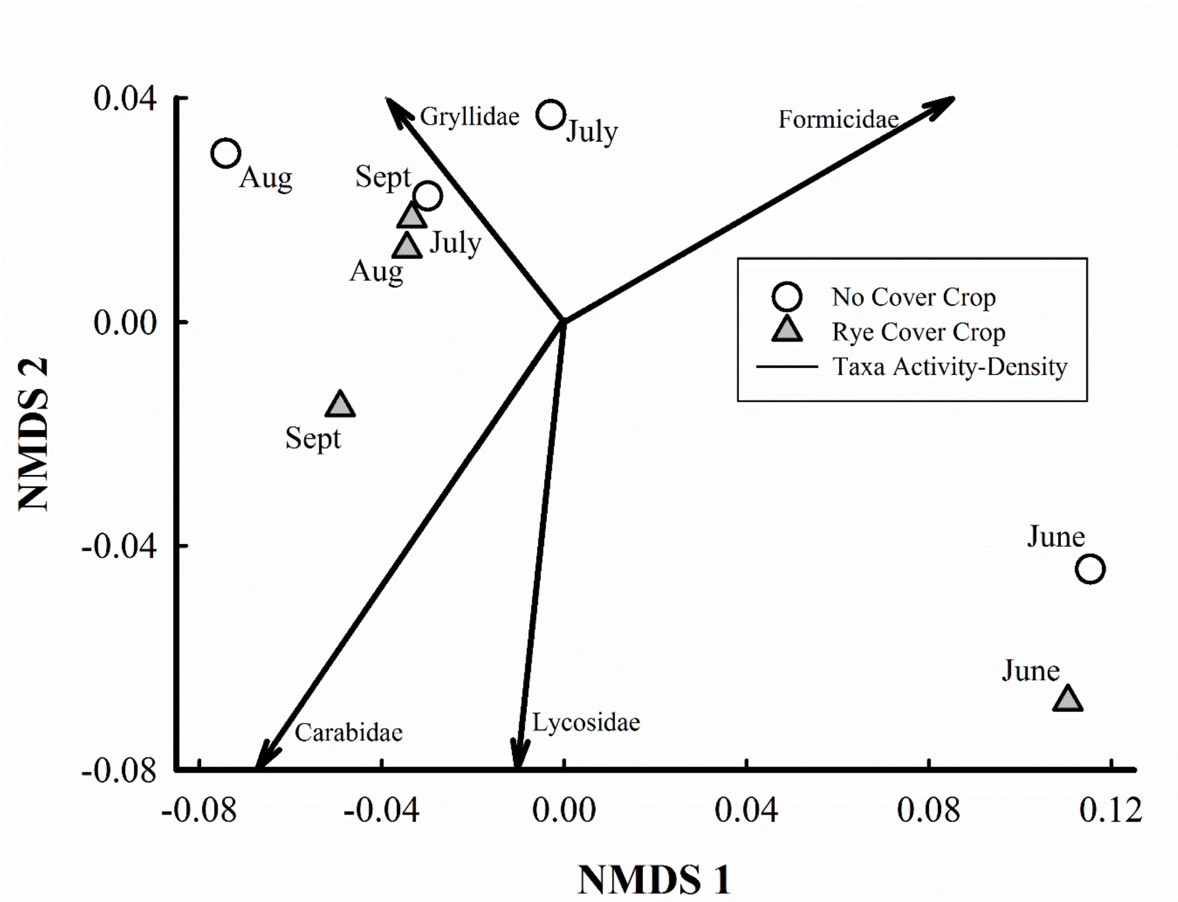
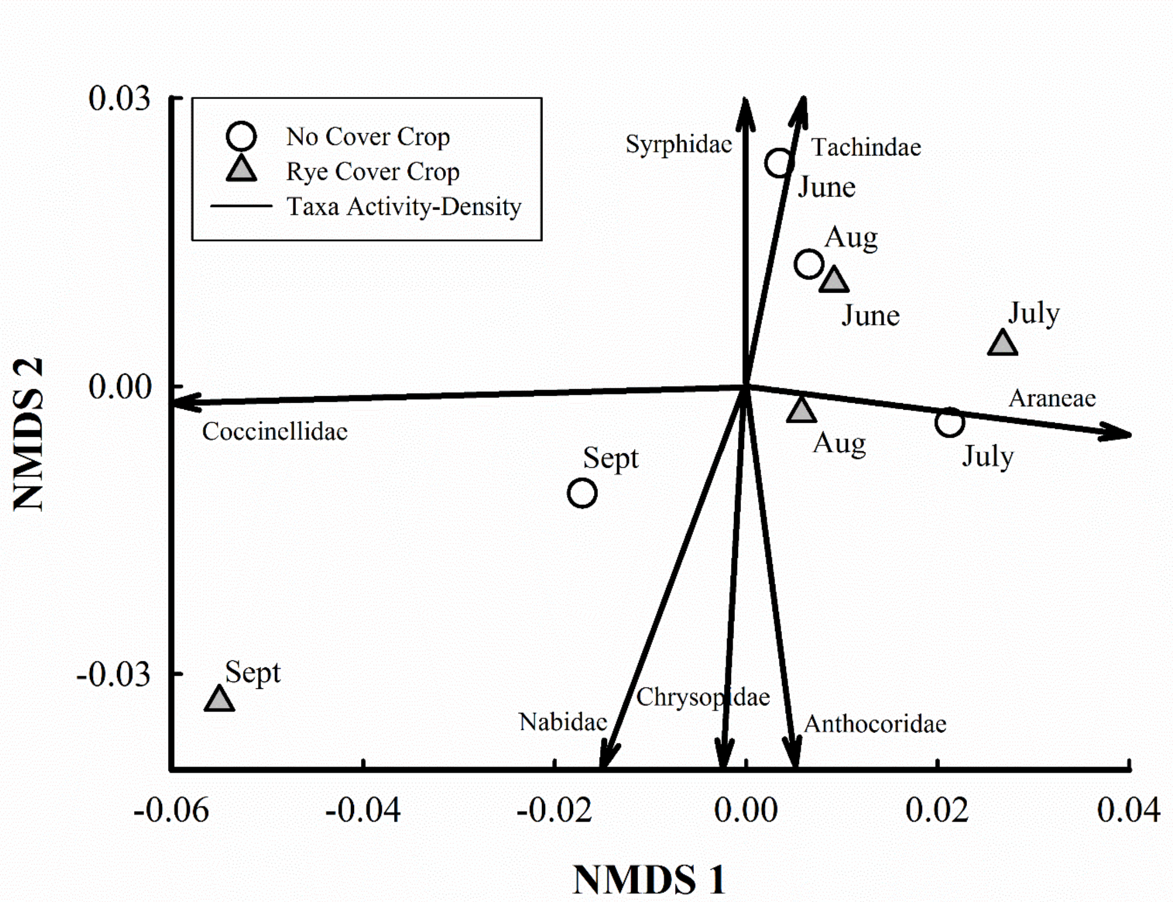

0.04
0.00
-0.04
-0.08
NMDS 2
-0.08
-0.04
0.00
0.04
0.08
0.12
NMDS 1
Gryllidae
Formicidae
Carabidae
Lycosidae
July
Aug
Sept
July
Aug
Sept
June
June
No Cover Crop
Rye Cover Crop
Taxa Activity-Density

Figure 3.


0.03
0.00
-0.03
NMDS 2
No Cover Crop
Rye Cover Crop
Taxa Activity-Density
Syrphidae
Tachindae
June
Aug
June
July
Araneae
Coccinellidae
Aug
July
Sept
Sept
Nabidae
Chrysopidae
Anthocoridae
-0.06
-0.04
-0.02
0.00
0.02
0.04
NMDS 1

Supplemental Table S1. Analysis of variance of individual taxa captured from corn and soybean plots by sampling method and crop

Sampling Method/		Cover Treatment			Sampling Date			Trt*Date		
Crop	Taxa	*F*	df	*P*	*F*	df	*P*	*F*	df	*P*
Pitfall trap / Corn	Diplopoda	2.04	1, 40	0.16	34.32	3, 135	**<0.0001**	0.80	3, 135	0.50
	Opiliones	0.08	1, 40	0.78	7.38	3, 135	**0.0001**	0.46	3, 135	0.71
	Lycosidae	0.04	1, 40	0.84	8.21	3, 135	**<0.0001**	0.48	3, 135	0.70
	Carabidae	0.94	1, 40	0.34	7.11	3, 135	**0.0002**	0.21	3, 135	0.89
	Formicidae	0.09	1, 40	0.77	9.62	3, 135	**<0.0001**	1.30	3, 135	0.28
	Gryllidae	0.76	1, 40	0.39	10.06	3, 135	**<0.0001**	1.58	3, 135	0.20
Pitfall trap / Soybean	Diplopoda	0.3	1, 41	0.59	18.29	3, 136	**<0.0001**	1.67	3, 136	0.18
	Lycosidae	2.36	1, 41	0.13	6.09	3, 136	**0.0006**	0.52	3, 136	0.67
	Carabidae	6.66	1, 41	**0.013**	7.38	3, 136	**0.0001**	2.27	3, 136	0.08
	Formicidae	0.01	1, 41	0.92	15.35	3, 136	**<0.0001**	0.87	3, 136	0.46
	Gryllidae	5.58	1, 41	**0.023**	20.67	3, 136	**<0.0001**	0.36	3, 136	0.78
Sweep net / Soybean	Araneae	0.94	1, 41	0.34	4.49	3, 137	**0.005**	0.77	3, 137	0.51
	Anthocoridae	0.21	1, 41	0.65	2.93	3, 137	**0.036**	0.33	3, 137	0.80
	Nabidae	1.08	1, 41	0.30	7.12	3, 137	**0.0002**	0.54	3, 137	0.66
	Chrysopidae	0.86	1, 41	0.36	8.72	3, 137	**<0.0001**	2.60	3, 137	0.06
	Coccinellidae	0.07	1, 41	0.79	5.56	3, 137	**0.001**	0.73	3, 137	0.54
	Chalcidoidea	0.01	1, 41	0.94	4.56	3, 137	**0.004**	1.31	3, 137	0.27
	Syrphidae	2.59	1, 41	0.12	2.14	3, 137	0.10	0.07	3, 137	0.98
	Tachinidae	0.39	1, 41	0.54	1.71	3, 137	0.17	0.80	3, 137	0.50