Impact of Land Management Practices on Carabids (Coleoptera: Carabidae) and Other Arthropods on the Western High Plains of North America

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Source: Southwestern Entomologist, 34(1):43-59.
Published By: Society of Southwestern Entomologists
https://doi.org/10.3958/059.034.0104
URL: http://www.bioone.org/doi/full/10.3958/059.034.0104

Impact of Land Management Practices on Carabids (Coleoptera: Carabidae) and Other Arthropods on the Western High Plains of North America

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Abstract. This study examined how land management practices can affect the abundance of several arthropods commonly found in agriculture. This work was done in plots that had been subjected to three successive years of an agronomic experiment that evaluated the effects of a wheat, *Triticum aestivum* L., cover crop or no cover crop on weed and water management. After the third growing season, pitfall traps were installed and arthropods were collected and identified. At one location, carabids (Coleoptera: Carabidae) were identified to genus. Four of the genera (*Amara, Anisodactylus, Harpalus,* and *Calathus*) were more common under no-till conditions. Only one genus *(Stenolophus)* was more common in tilled plots. Five genera (*Amara*, *Bradycellus, Scarites, Stenolophus,* and *Calathus*) were more common in plots with a history of more weeds caused by less herbicide use. Carabids were not more abundant in plots with fewer weeds after herbicides had been applied. Past presence of a winter cover crop never reduced carabid numbers, but significantly increased members of two genera *(Harpalus* and *Poecilus).* As a group, carabids at one location were more common in plots without a history of a cover crop. At another location, more carabids were in tilled than nontilled plots. Crickets (Orthoptera: Gryllidae) were more common under no-till conditions. At all locations, wolf spiders (Araneae: Lycosidae) were more common in plots with no tillage and a previous cover crop. Results suggested that surface residues affected carabids, wolf spiders, and crickets.

Introduction

Ground beetles (Coleoptera: Carabidae) are common in annual cropping systems. These beetles spend most of their lives on the soil surface or in surface litter and are important biological control agents for insect and weed pests of crops (Clark et al. 2006, Hatten et al. 2007). They are generalist predators that prey on insect crop pests, and some carabids influence weed abundance and weed species composition by eating seeds (Brust and House 1988). Because of the important roles of these carabids, there is interest in managing land to maximize the abundance and diversity of carabid fauna. It is believed that carabid abundance and diversity will decrease as the magnitude and severity of land management and human disturbance increase. Brust and House (1988) showed that reduction of pesticides, use of crop rotation, cover crops, manure, and reduced or no-till crop practices promoted abundance of ground beetles.

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Wolf spiders (Araneae: Lycosidae) are important in agroecosystems because they prey on pests and contribute to overall biodiversity (Oberg 2007). Like carabids, abundance of wolf spiders increases as land management decreases (Schmidt et al. 2005).

Crickets (Orthoptera: Gryllidae) are seed and seedling consumers in agroecosystems. Common species of crickets eat weed seeds (Brust and House 1988, Carmona et al. 1999). During the late summer, crickets consumed 70 to 100% of seeds of giant foxtail, *Setaria faberi* Herrm., within maize, *Zea mays* L., and soybean, *Glycine max* L., field plots (O'Rourke et al. 2006). However, little research has been done to explore how land management may affect crickets.

A winter cover crop reduces soil erosion and water runoff and improves water infiltration, water retention, soil tilth, and soil carbon and nitrogen content (Teasdale 1996, Yenish et al. 1996, Sainju and Singh 1997, Mallory et al. 1998, Varco et al. 1999, Currie and Klocke 2005). The additional food and shelter offered by cover crops may also increase the abundance of ground beetles. Carmona and Landis (1999) reported that carabids were captured in consistently larger numbers in plots with a cover crop than in plots without. Hummel et al. (2002) found that carabids and wolf spiders seemed more active and numerous in plots that had ground cover than in those without it.

Effects of herbicides on carabid or wolf spider abundance or diversity have received little attention. Hough-Goldstein et al. (2004) found that reduced applications of glyphosate were associated with increased weediness and increased abundance of a common carabid, *Harpalus pensylvanicus* De Geer, but had no effect on wolf spiders. Where cover crops were killed by mowing or herbicide, several carabid species and wolf spiders were more numerous early in the season (Laub and Luna 1992).

Tillage effects on carabid and wolf spider communities have been studied more extensively. In a conventional tillage system the physical, chemical, and biological properties of soils are disturbed, which may be detrimental to carabids (Hatten et al. 2007). Conversely, use of a no-till system benefits growers by reducing production costs and soil compaction; in addition, reduced tillage preserves the vertical structure of the soil profile, moderates soil temperatures, and conserves organic matter and soil moisture (Kladivko 2001). Compared with conventional tillage systems, no-till systems are generally associated with increased abundance of ground beetles (Brust et al. 1985, Stinner and House 1990, Anderson 1999, Holland and Reynolds 2003). In an experiment comparing strip tillage (tillage confined to narrow bands where the seed is planted) and conventional tillage, significantly more wolf spiders were in the strip-tilled band during 2 of 4 years (Hummel et al. 2002). The objective of this experiment was to determine the combined effects of a history of cover cropping versus no cover cropping in maize, a history of different weed densities resulting from different rates of herbicide treatment, and tillage or no tillage on the abundance of carabid beetles, wolf spiders, and crickets.

Materials and Methods

This research was an extension of a weed and water management study established by Currie and Klocke (2005). The agronomic experiment included a cover crop of winter wheat, *Triticum aestivum* L., or without, and weed density manipulated by varying herbicide rates (no, medium, or high) for a total of six treatment combinations (Currie 2003, 2004). The treatments were assigned to plots (9 x 14 m) in a completely randomized design with five replications. The experiment was repeated at three locations, referred to as Locations 1, 2, and 3, each initiated in successive years (1997, 1998, 1999) and located within a 53-ha center-pivot irrigated field at the Kansas State University Southwest Research & Extension Center at Garden City, KS. At Location 1, maize was planted in 1998, 1999, and 2000. At Location 2, maize was planted in 1999, 2000, and 2001. At Location 3, maize was planted in 2000, 2001, and 2002. The same unique randomized design was used all 3 years at each location. The field had been used for non-weed control research for more than 10 years before this experiment. One year before maize was planted (1997, 1998, and 1999), the plot area was moldboard plowed to a depth of 450 mm and maintained weed free using 0.83 kg ai ha^{-1} applications of glyphosate as needed for one summer. During the first week of October, winter wheat ('Tam 107') was drilled at 100 kg ha^{-1} in three of the six plots in each of the five replications of the cover crop. In spring when wheat reached the boot stage (first week of May), all plots were sprayed with 0.83 kg ha^{-1} of glyphosate to kill the wheat in the cover crop plots and any weeds growing in the non-cover crop plots. Atrazine at 0.0, 0.8, and 1.6 kg ha^{-1} referred to as no, medium, and high herbicide rates, respectively, was applied immediately after planting maize in the spring.

After each of the 3-year cover-crop agronomic experiments was completed, a follow-up experiment was used to measure the long-term effects of a single tillage event on the abundance and diversity of arthropods. After maize was harvested from the previous experiment (2000, 2001, and 2002), each of the six plots was split from east to west into two sub-plots. One sub-plot in each plot was randomly selected for tillage by two passes with a tandem disk. This tillage removed an estimated 75% of surface residue based on a residue conservation model (Dickey 1986).

After tillage, no plants were in the plots because plots were sprayed every 2 weeks with glyphosate. Only residue left from the 3 years of growing maize and weeds and weed seedlings that may have emerged between glyphosate applications were in the plots. One pitfall trap was installed in the center of each sub-plot. These traps consisted of a 13-cm-diameter, 0.3-m-long section of standard 80 PVC pipe inserted into a hole in the ground until the top of the tube was flush with the ground surface. Inside each plastic tube a 296-ml plastic drinking cup (P-10, Solo Cup Company, Urbana, IL) with the bottom removed served to funnel insects into a 473-ml plastic drinking cup (P-16, Solo Cup Company, Urbana IL) in the bottom of the plastic tube. About 150 ml of polyethylene glycol automobile antifreeze was added as a preservative to each trap. A square of masonite with 1.0-cm legs was installed over each pitfall trap, leaving a 0.5-cm gap between the ground and bottom of the masonite. This cover allowed ground-dwelling arthropods to enter the traps but kept out excess soil, water, and small vertebrates. Pitfall traps were monitored every 2 weeks in the spring and summer and once a month during the late fall and winter. To preserve the insects for identification, traps were also collected when there was a rain or snow event. After any such event, traps were emptied and new antifreeze was added. Insects from the pitfall traps were taken into a laboratory and identified. Carabids collected from Location 1 during Year 1 (2000 to 2001) were identified to genus. Voucher specimens for the first season were identified to species by one of the authors (BWF). In the following years, specimens were identified only to family.

Data for the 10 carabid genera (first season) and carabids from each season were analyzed as a three-factorial analysis of variance with two levels of cover-crop history (cover and no cover), three amounts of weed residue caused by three herbicide rates (none, medium, and high), and two amounts of tillage (tilled and not tilled) (SAS Institute 2002). Means were separated by LSD.

Results

A total of 7,702 carabid specimens representing 20 genera was collected from Location 1 in 2000-2001 (Table 1). Although the carabids were not analyzed by species, many of the specimens were identified to species. The most common genus was *Amara*, comprising almost 50% of the total specimens collected. The 10 most common genera accounted for 98.5% of the total specimens collected. This included *Amara (*A. *impuncticollis* Say and *A. pennsylvanica* Hayward), *Harpalus* (*H. amputatus* Say and *H. pensylvanicus* De Geer), *Bradycellus* (*B. rupestris* Say)*, Stenolophus* (*S. comma* Fabricius and *S. lineola* Fabricius)*, Elaphrus* (species not identified)*, Scarites* (*S*. *subterraneus* Fabricius)*, Anisodactylus* (*A*. *carbonarius* Say and *A. sanctaecrucis* Fabricius)*, Poecilus* (*P. chalcites* Say)*, Calathus* (*C. opaculus* LeConte), and *Bembidion* (*B. quadrimaculatum* Linnaeus). The less commonly collected genera were *Lebia* (*L. atriventris* Say and *L. solea* Hentz), *Calosoma* (*C*. *externum* Say), *Cyclotrachelus* (*C. torvus* LeConte, 1863), *Pterostichus* (*P. femoralis* Kirby), *Chlaenius* (*C. emarginatus* Say and *C. nemoralis* Say), *Microlestes*

Table 1. List of Carabid Genera Collected from Location 1, October 2000-August 2001

Genus	Season total of specimens	Percentage of total collected
Amara	3,802	49.4
Harpalus	969	12.6
Bradycellus	777	10.1
Stenolophus	750	9.7
Elaphrus	533	6.9
Scarites	358	4.6
Anisodactylus	211	2.7
Poecilus	94	1.2
Calathus	67	0.8
Bembidion	35	0.5
Lebia	32	<0.5
Calosoma	19	<0.5
Cyclotrachelus	16	<0.5
Pterostichus	15	<0.5
Chlaenius	8	<0.5
Microlestes	7	<0.5
Abacidus	5	<0.5
Cicindela	2	<0.5
Euryderus s	1	<0.5
Pasimachus	1	<0.5
Total	7,702	100

(*M. nigrinus* Mannerheim), *Abacidus* (*A. permundus* Say), *Cicindela* (*C. punctulata* Olivier), *Euryderus* (*E. grossus* Say), and *Pasimachus* (*P. elongates* LeConte). Nomenclature of the carabids was retrieved from the Integrated Taxonomic Information System (2008). All were common North American carabid genera (Arnett 1963, Luff 2002).

At Location 1, four of the 10 genera were significantly affected by tillage (Table 2). Significantly more *Amara, Anisodactylus, Harpalus*, and *Calathus* were trapped in no-till than tilled sub-plots (Table 3). However, more *Stenolophus*, were found in tilled sub-plots. Five of the 10 genera (*Amara, Bradycellus, Scarites, Stenolophus,* and *Calathus*) also were affected by herbicide-induced changes in the history of weed abundance. *Amara, Stenolophus,* and *Calathus* were significantly affected by differences in weed abundance. Only *Amara, Stenolophus,* and *Calathus* were affected by tillage (Table 2). Plots with a history of increased weed abundance resulting from no atrazine application had more carabids for five of the 10 genera than did plots with fewer weeds (Table 3). Presence of a cover crop resulted in significantly more *Harpalus* and *Poecilus* (Tables 2 and 3). Statistical analysis showed significant interactions between treatment factors for two genera, and interactions approaching significance for two other genera (Table 2). For *Amara*, *Calathus,* and *Harpalus,* there was a two-way interaction between tillage and herbicide-induced weed density. Numbers of *Amara* were significantly larger in no-till sub-plots than in tilled sub-plots and were significantly larger in plots with a history of decreased weed abundance (Fig. 1A). This suggests that past use of atrazine to control weeds had no negative effects on this genus. Numbers of *Amara* were statistically equal among the plots with different amounts of weeds (Table 3). Results for *Amara* were similar for *Calathus* (Fig. 1B).

Table 2. *P*-values for the Three-factor Analysis of Variance for Carabid Genera Collected from Location 1, October 2000-August 2001

Genus	*P*-Values [a]			
	Tillage	Weed density	Cover crop history	Interactions
Amara	<0.0001	0.002	0.784	Till*Weed 0.015
Anisodactylus	0.025	0.576	0.241	Till*Weed*Cover 0.039
Bradycellus	0.533	0.087	0.955	N.S.
Elaphruys	0.496	0.626	0.102	N.S.
Harpalus	<0.0001	0.398	0.003	Till*Weed 0.084 Till*Cover 0.079
Scarites	0.320	0.072	0.943	N.S.
Stenolophus	0.095	0.004	0.521	N.S.
Bembidian	0.686	0.457	0.762	N.S.
Calathus	<0.0001	0.031	0.59	Till*Weed 0.067
Poecilus	0.507	0.655	0.072	N.S.

[a]2 amounts of tillage, 3 of weed abundance, and 2 amounts of cover crop

Table 3. Mean Number of Carabids Collected Throughout the Sampling Year for the Three Treatment Factors, Location 1, October 2000-August 2001

Genus	No tillage	Tillage	Abundant weeds (no herbicide)	Moderate weeds (0.8 kg ha^{-1} herbicide)	Few weeds (1.6 kg ha^{-1} herbicide)	No cover-crop history	Cover-crop history
Amara	79.6 a	40.2 b	79.2 a	51.5 b	49.1 b	60.9 a	58.9 a
Anisodactylus	7.5 a	2.3 b	4.8 a	6.4 a	3.5 a	3.5 a	6.2 a
Bradycellus	11.4 a	12.9 a	15.7 a	11.4 ab	9.4 b	12.2 a	12.1 a
Elaphruys	9.6 a	8.1 a	10.4 a	8.2 a	8.0 a	7.0 a	10.7 a
Harpalus	22.4 a	9.2 b	16.8 a	16.8 a	13.8 a	12.5 b	19.0 a
Scarites	6.4 a	5.5 a	7.5 a	5.4 b	5.0 b	6.0 a	5.9 a
Stenolophus	10.8 b	13.7 a	16.5 a	10.0 b	10.3 b	12.8 a	11.7 a
Bembidian	0.8 a	1.0 a	1.0 a	0.4 a	1.4 a	0.8 a	1.0 a
Calathus	1.9 a	0.2 b	1.8 a	0.9 b	0.6 b	1.2 a	1.0 a
Poecilus	1.7 a	1.4 a	1.4 a	1.8 a	1.6 a	1.2 b	1.9 a

Means followed by the same letter within a treatment factor (tillage, weed density, or cover crop) in the same row are not significantly different (<0.05), LSD.

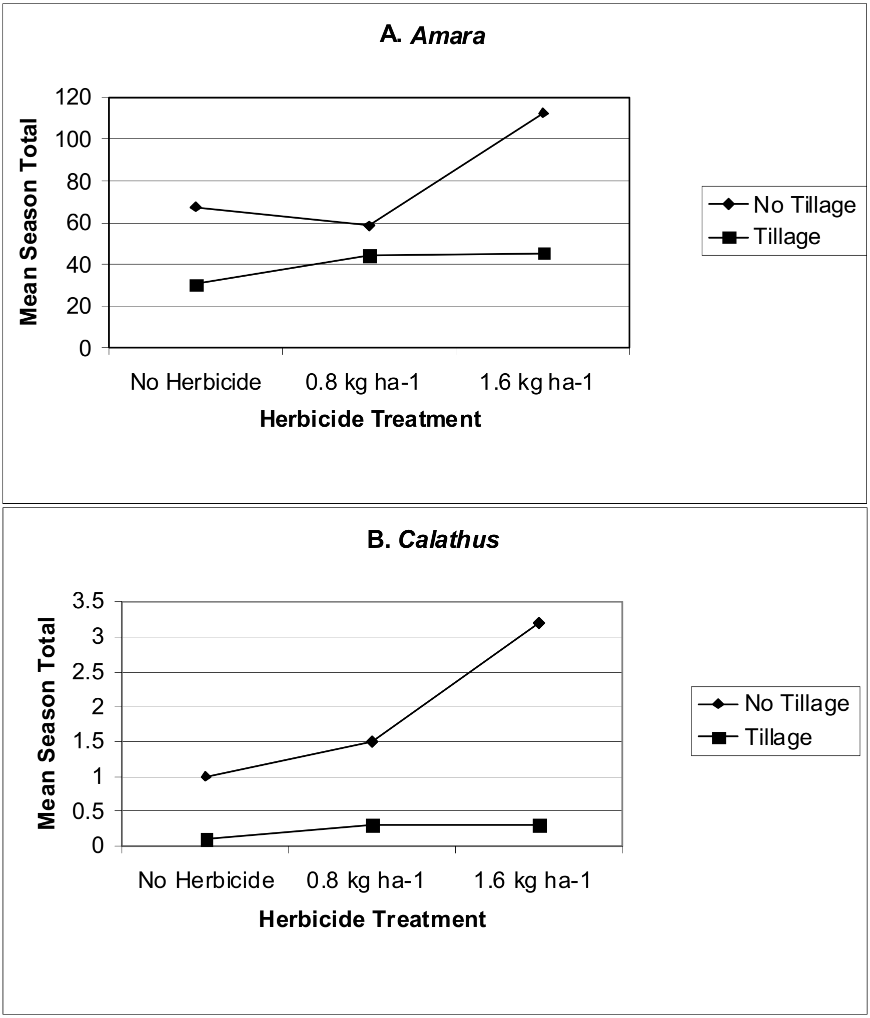

Fig. 1. Interactions between tillage and history of herbicide-induced weed density on (A) *Amara and* (B) *Calathus.*

For the genus *Harpalus,* numbers were similar for the high and moderate amounts of weeds, with more carabids trapped in no-till plots (Fig. 2A). With fewer weeds, fewer insects were in the no-till sub-plots, whereas numbers of insects in tilled sub-plots were slightly larger. For *Harpalus*, there was also a two-way interaction between tillage and history of a cover crop (Table 2). The trend was strongest with no-till plots, and numbers of carabids increased with the residues created by a previous cover crop (Fig. 2B).

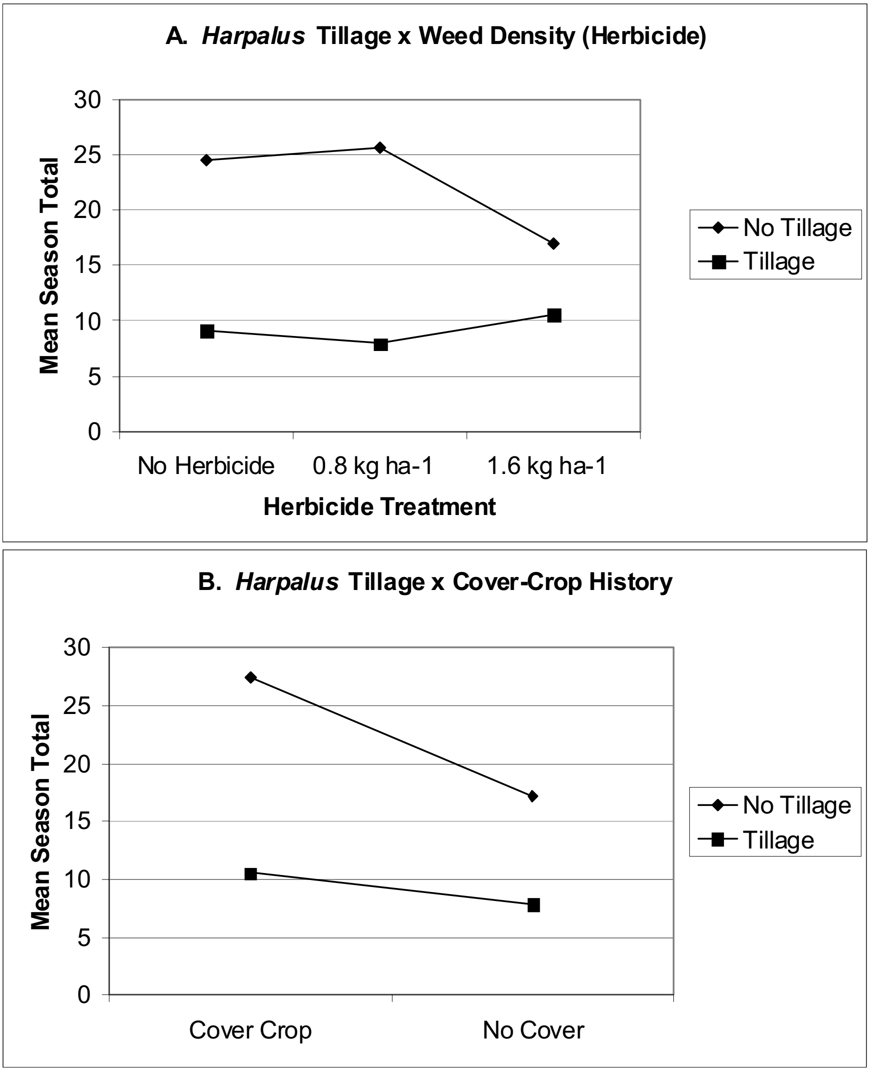

Fig. 2. Interactions between (A) tillage and history of herbicide-induced weed density and (B) tillage and history of winter cover crop on *Harpalus.*

For the genus *Anisodactylus*, there was a significant interaction between all three treatment factors (Table 2). However, these interactions seemed more random (Figs. 3A and 3B). The only meaningful trend was more *Anisodactylus* beetles in no-till than in tilled sub-plots.

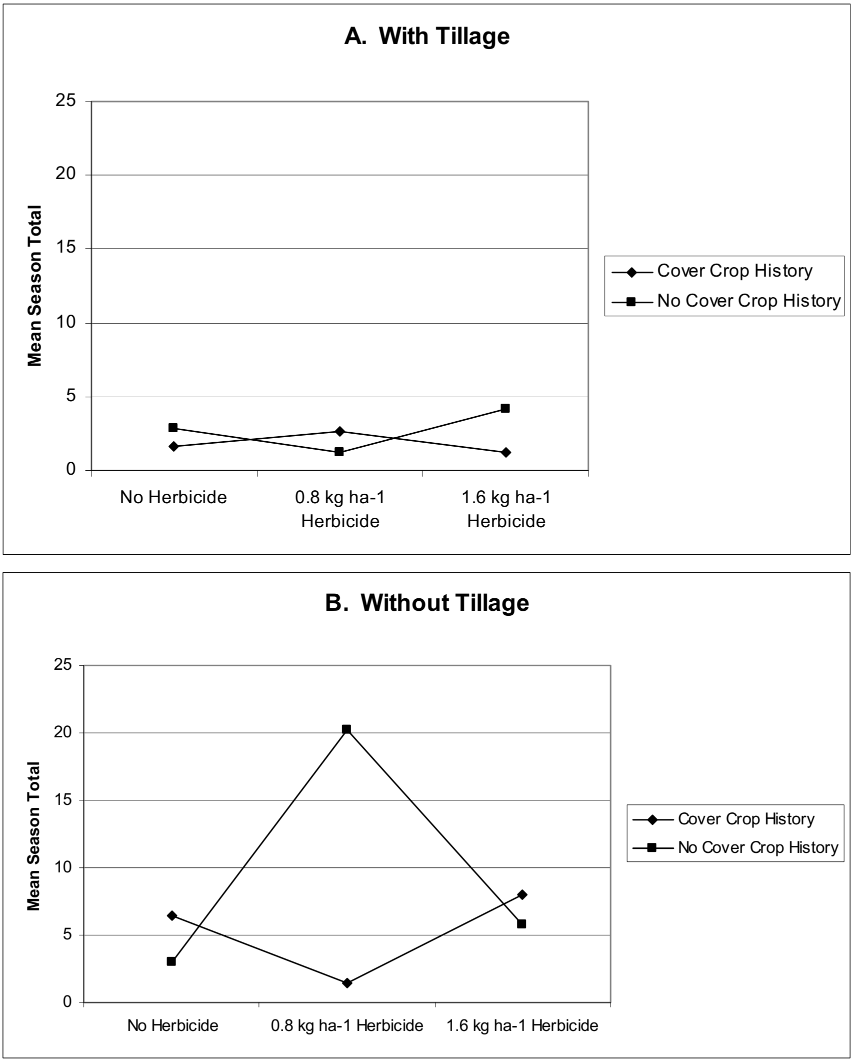

Fig. 3. Three-way interactions among tillage, history of herbicide-induced weed density, and history of winter wheat cover crop on *Anisodactylus* (A) with a history of tillage and (B) without a history of tillage.

All of the carabid genera from Location 1 were grouped into one family for further analysis; the same was done at Locations 2 and 3. At Location 1, carabids were collected more frequently in sub-plots with no tillage, whereas at Location 3, carabids were collected more frequently where there was tillage (Table 4). At Location 1, significantly more carabids were collected from sub-plots with more weeds resulting from no herbicide use. At Location 2, significantly more carabids were collected in plots with no history of a winter cover crop.

Significantly more wolf spiders were collected at all locations in sub-plots with a history of no-till and in plots with history of a cover crop (Table 4). There was a significant two-way interaction between tillage and weed density in one of three locations. Wolf spiders were most common in no-till sub-plots with increased weeds created by lack of herbicide (Fig. 4). The largest number of wolf spiders was found in no-till sub-plots with a history of increased weeds resulting from no herbicide use. Differences in numbers of wolf spiders between tilled and no-till plots decreased with few weeds. As for Carabidae, the tillage effect may have been buffered by changes in weed biomass produced by previous use of atrazine.

Crickets responded only to differences in tillage treatments (Table 4). More crickets were collected in no-till sub-plots than in tilled sub-plots. As for *Amara, Calathus, and Harpalus,* the past history of atrazine use had little effect on the number of crickets collected in traps.

Seasonal distribution of carabids differed among genera (Figs. 5A, 5B, and 5C). The most commonly collected genus, *Amara,* was present in large numbers all year, including January, and peaked in abundance during April and May. All other genera were scarce or inactive during the winter. *Harpalus, Bradycellus, Calathus,* and *Bembidion* seemed to peak during the early spring (April and May). Other genera such as *Stenolophus, Elaphrus, Anisodactylus,* and *Poecilus* were most abundant in June and July. *Scarites* was most common in late summer and into fall. Many of the less common genera were most abundant during the summer, but were too scarce to indicate a seasonal trend.

Discussion

It is important to emphasize that in this experiment, it was the histories of different agronomic treatments and their effects on the types and amounts of residues, to which the arthropods were exposed, not the treatments themselves. At the end of the agronomic study, there were large differences in the amounts of residue in the different plots. Currie and Klocke (2005) reported maize yield and weed and cover-crop biomass for the different treatments during the 3-year agronomic study. They reported that maize yielded consistently more in plots treated with the high rate of atrazine and grown with a winter wheat cover crop. These plots also had fewest weeds, almost 100% control in two of nine location-years. Because amount of residue remaining in the field was correlated with grain yield, plots with atrazine and a cover crop would have had the most maize residue. Application of atrazine resulted in a 15-fold reduction in weed biomass and masked any weed control effects created by the cover crop. Plots with no herbicide and no winter cover crop consistently yielded less grain and had most weed biomass. Plots with the most weeds would also have had the most weed seeds because of correlation between the biomass of a weed and its seed production (Massinga et al. 2001). Plots with the most weeds would have had less total residue because weeds produce less biomass than maize (Massinga and Currie 2002). Tillage reduces surface residue by an estimated 75% (Dickey et al. 1986). Thus, there was a wide range in the amounts of residue and weed seed on the surface of the different plots to which the soil arthropods could respond. During the growing

Table 4. *P*-values for Three-Factor Analysis of Variance for Carabids (Coleoptera: Carabidae), Wolf Spiders (Araneae: Lycosidae), and Crickets (Orthoptera: Gryllidae) Collected from Locations 1, 2, and 3

	P-values				Means						
	Tillage	Weed density	Cover-crop history	Inter-actions	No tillage	Tillage	Abundant weeds (no herbicide)	Moderate weeds (0.8 kg ha^{-1} herbicide)	Few weeds (1.6 kg ha^{-1} herbicide)	No cover-crop history	Cover-crop history
Coleoptera: Carabidae											
Location 1	<0.0001	0.0005	0.336	N.S.	152.1 a	94.5 b	155.0 a	112.6 b	102.4 b	118.1 a	128.5 a
Location 2	0.724	0.829	0.010	N.S.	323.8 a	315.7 a	316.8 a	313.2 a	329.5 a	350.6 a	289.0 b
Location 3	0.031	0.298	0.527	N.S.	117.6 b	148.4 a	133.6 a	119.3 a	146.0 a	128.6 a	137.4 a
Araneae: Lycosidae											
Location 1	<0.0001	0.474	0.014	Till*Weed 0.051	47.9 a	25.1 b	38.8 a	35.7 a	35.0 a	33.1 b	39.9 a
Location 2	<0.0001	0.889	0.047	N.S.	18.8 a	10.7 b	14.5 a	14.5 a	15.4 a	13.0 b	16.5 a
Location 3	0.002	0.801	0.043	N.S.	11.90a	8.0 b	10.5 a	9.8 a	9.6 a	8.8 b	11.2 a
Orthoptera: Gryllidae											
Location 1	0.0002	0.969	0.852	N.S.	22.7 a	14.6 b	18.4 a	19.0 a	18.6 a	17.1 a	20.2 a

Means followed by the same letter within a treatment factor (tillage, weed density, or cover crop) in the same row are not significantly different (<0.05), LSD.

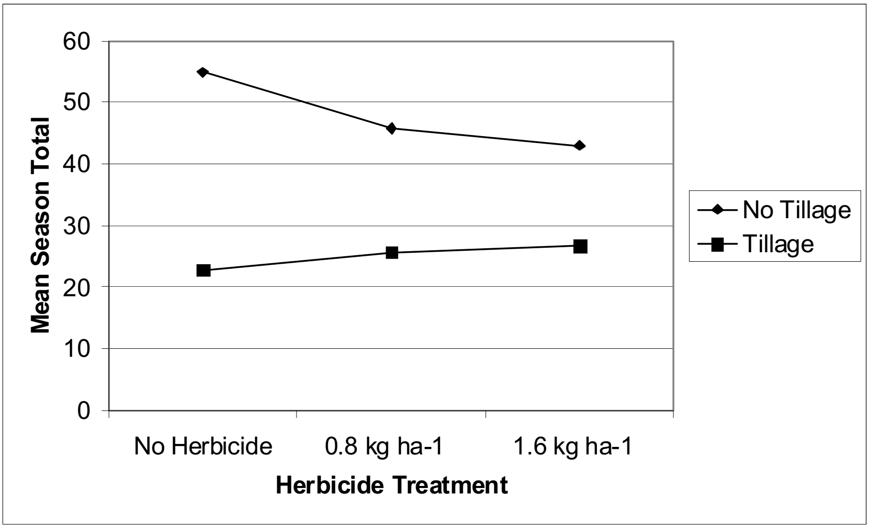

Fig. 4. Interactions between tillage and history of herbicide-induced weed density for wolf spiders.

season, when the pitfall traps were being used, all plots were sprayed on a biweekly basis with glyphosate. This left little living plant matter for arthropods, and there was no new production of weed seed.

Numbers of beetles in the genera *Amara, Anisodactylus*, *Harpalus,* and *Calathus* were larger in no-till than in tilled plots. These carabids are known to prefer habitats with increased humidity, possibly because these habitats are better suited for oviposition or for larval development (Holland 2002). It was not surprising that almost half of the carabid genera in this experiment were more abundant in the no-till sub-plots than in tilled plots. Many studies have shown that ground arthropods are more abundant in no-till than in tilled plots (Brust et al. 1985, Stinner and House 1990, Anderson 1999, and Holland and Reynolds 2003). Seeds left behind in weedy plots may also have provided an important food source for some of these insects (Holland 2002, Tooley and Brust 2002). This is especially true for *Amara*, *Anisodactylus,* and *Harpalus* that as larvae and adults rely on seeds for food (Luff 2002). Another potentially important factor could be the ability of the carabids to reach the seeds left behind by various weeds. White et al. (2007) found that beetles in the genera *Amara* and *Anisodactylus* consumed more seeds of both Palmer amaranth, *Amaranthus palmeri* S., and velvetleaf, *Abutilon theophrasti* Medik., when the seeds were placed on the soil surface versus 1.0 cm below the soil surface. Tillage would incorporate many seeds into the soil where they would not be as readily available to omnivorous carabids. The genus *Calathus* feeds on invertebrates in all life stages and may find more food in no-till plots (Luff 2002). The genus *Stenolophus* was collected more frequently in tilled plots, although this was only significant at P = 0.095. This genus includes the seedcorn beetle, *Stenolophus lecontei* Chaudoir, that feeds on germinating maize seed or young

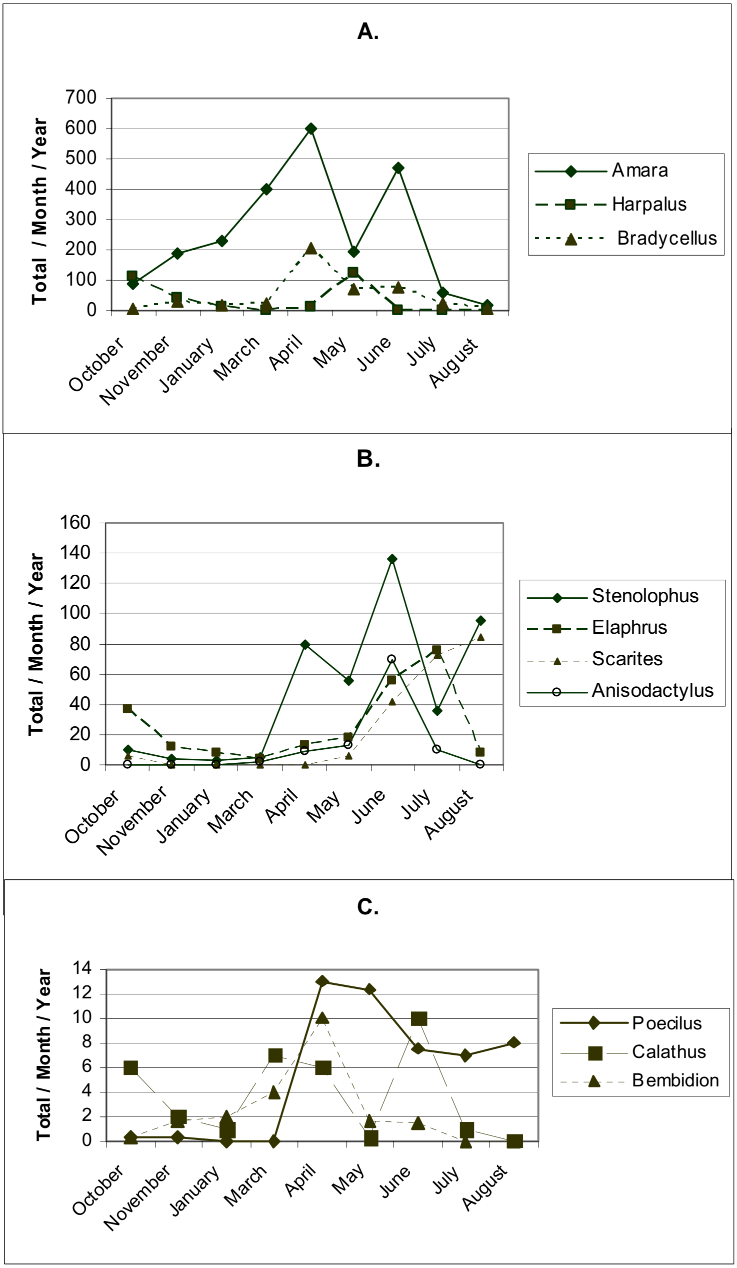

Fig. 5. Seasonal occurrences of the 10 most common carabid genera (A) *Amara, Harpalus, Bradycellus*, (B) *Stenolophus, Elaphrus, Scarites, Anisodactylus,* (C) *Poecilus, Calathus,* and *Bembidion* collected at Location 1.

plants. As an adult, it feeds on other insects (Pope 1998). Tillage is commonly used by growers to make unharvested maize seed germinate so it will not be a weed in the upcoming crop. If the tilled plots in this experiment had germinating maize seed, the plots would be a better habitat for the larval seedcorn beetles.

Amara, Bradycellus, *Scarites, Stenolophus*, and *Calathus* were more abundant in the plots with more weeds. The herbicides used in the agronomic study, atrazine and glyphosate, have low toxicity to insects. It is unlikely they could have directly killed or had any residual effect on the carabids. Wheat planted as a cover crop in the plots showed no herbicide injury symptoms. Wheat is so sensitive to atrazine that it is used as an indicator of atrazine in the soil. In fact, measurements of wheat biomass in this study were often increased when there was a past history of atrazine (Currie and Klocke 2005). This could be due to reduced water loss by weed growth, which would leave more water in the soil to be used by the wheat. Insect responses to herbicide treatment were more likely due to fewer weeds and depleted seeds. As discussed, weed seeds are food for many genera of carabids. It is also possible that some carabids such as *Scarites*, *Stenolophus,* and *Calathus* attracted to plots with weed seeds preyed on other seed-eating invertebrates. This would have created a food source for carabids that feed on other insects (Luff 2002). *Bradycellus* is a diverse genus with different species common to different habitats. The species collected during this experiment were probably those that prefer surface residues.

Although the historical use of a winter wheat cover crop never resulted in fewer carabids, it resulted only in significantly more *Harpalus* and *Poecilus*. As discussed previously, the genus *Harpalus* is known to prefer habitats with more ground cover. However, Currie and Klocke (2005) reported that presence of a cover crop reduced weeds at least three-fold in the absence of atrazine. This means there would be fewer seeds for this omnivorous genus. In plots with cover crop alone, this three-fold reduction did not provide commercially acceptable amounts of weed control, so there probably was some seed present. Where a cover crop and atrazine were used together, weeds were reduced 15-fold. During two of the nine location-years, 100% of weeds were controlled with this combination. *Poecilus* was more commonly found in the plots with a history of a cover crop, although it was significant only at $P = 0.07$. Individual species within the genus *Poecilus* have different habitat preferences (Carmona and Landis 1999). Results of this experiment may show *Poecilius* to be more common in cover crops because of increased ground debris.

The complex relationship between carabid genera and ground residues is further explained by the two-way interactions found for three genera. For *Amara* and *Calathus,* most insects were recorded in plots with no tillage and high rates of herbicide. These plots would have had an environment with little weed biomass, but some seed and plant residue would have been available on the soil surface. Although these two genera feed on weed seeds and, therefore, would be expected to prefer plots with more weeds, the plots may supply plenty of food while creating a more favorable habitat in terms of availability of food, hiding places, and acceptable oviposition sites. *Harpalus* was found more frequently in no-till plots with a history of more weeds created by no herbicide application and a history of a cover crop. This would create a ground environment with some weed control provided by the cover crop, but there would still be plenty of seeds and plant residue left on the soil surface. This matches the previously described ideal environment for *Harpalus* (Brandmayer 1990, Holland 2002).

At Location 2, most carabids were collected from plots with no previous history of a cover crop. This location was the least productive of the three (Currie and Klocke 2005). This was attributed to less water-use efficiency. This may have been due to a less uniform water intake that occurred because of the larger slope, less sand content, and larger irrigation application rates that caused more water runoff. Less maize yield and dry matter from the wheat cover crop would result in less residue on the surface and fewer desirable habitats for the carabids than at Location 1.

At Location 3, more carabids were collected in tilled than not-tilled plots. Even with tillage, a number of different residue types can be present. Results from Locations 2 and 3 suggest that the diversity of carabids may make it difficult to draw general conclusions about the entire family. Results for this experiment suggest that either carabids as a family do not respond to tillage or more work is needed to define the effect on individual carabid genera and species.

Wolf spiders followed more closely the trend of past research. However, different amounts of herbicide-induced weeds did not affect abundance of spiders at any location. These results further support the work of Hummel et al. (2002) who showed that wolf spiders preferred weedier habitats with more ground cover. This could be because insects and other food for these spiders may be more common or easier to locate under no-till conditions with a cover crop.

Numbers of crickets differed only between plots with or without tillage. Crickets were more common in no-till than tilled plots. Crickets could be feeding on weed seed and with seed-feeding carabid genera, may have been collected more frequently in plots not tilled because it was easier to obtain seed on the soil surface rather than having to locate seeds that had been tilled into the soil.

Acknowledgment

We thank Jennifer Wright, Ruby J. Long, Kurt Aleks Schaefer, and Brady Reichmuth for installing pitfall traps, monitoring them throughout the experiment, and identifying specimens. We also thank Matt Hicks and Steve Michel for supervising the experiment. Contribution No. 09-147-J from the Kansas Agricultural Experiment Station.

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