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Diversity and Dominant Species of Ground Beetle Assemblages (Coleoptera: Carabidae) in Crop Rotation and Chemical Input Systems for the Northern Great Plains

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ABSTRACT Dominant carabid species present in crops and crop rotation sequences commonly used in the northern Great Plains were assessed as an initial step toward the management of carabids as natural control agents. Ground beetle populations were determined by pitfall trapping in 4 crop rotation treatments maintained under high, managed, and low levels of chemical fertilizer and pesticide inputs. Diversity and species richness among crops, rotations, and input levels were compared using 3 indices—the Shannon-Weaver Index, relative diversity, and the Hierarchical Richness Index (HRI). Four carabid species, *Cyclotrachelus alternans* (Casey), *Poecilus lucublandus* Say, *Harpalus pensylvanicus* (DeGeer), and *Bembidion quadrimaculatum* L., comprising ≈80% of the total collected, were considered dominant species. When carabid abundance data were grouped by crop, *C. alternans* was the dominant species in corn and alfalfa and *P. lucublandus* was dominant in wheat. In soybean plots, *C. alternans* and *P. lucublandus* were equally abundant. The relative abundance of *H. pensylvanicus* was highest in the low-input plots. High values of HRI for carabid diversity and species richness in the managed plots suggested that reduced chemical inputs encouraged greater abundance and diversity of beneficial carabids than were found in the high-input plots without the loss of yield seen in the low-input plots.

KEY WORDS Carabidae, ground beetles, species diversity, dominance, hierarchical richness index, cropping systems

GROUND BEETLES (Coleoptera: Carabidae) often occur abundantly in field crops in spite of disturbance of the soil by tillage operations and frequent changes in vegetation associated with rotational production systems (Thiele 1977). The polyphagous habits of carabids (Best and Beegle 1977, Kirk 1982) as predators of pest insects (Floate et al. 1990, Winder 1990) and consumers of plant material (Johnson and Cameron 1969), particularly weed seeds (Lund and Turpin 1977, Brust 1993), have been documented. Carabids generally are regarded as beneficial insects, and the predaceous feeding habit of many species stimulates interest in their potential as natural pest control agents in agricultural settings (Allen 1979).

Tonhasca (1993) suggested that carabid assemblages in agroecosystems be treated as communities in early successional stages because of the seasonal disturbances to the environment associated with tillage and other field operations. Tonhasca (1993) also observed that samples from carabid communities often are composed of a few dominant species that contribute ≈80% of the total, as is characteristic of early successional communities (May 1981). Furthermore, the dominant species present in agricultural habitats may vary depending on the diversity and management intensity of a particular agricultural system. Kirk (1971) cataloged ground beetles from agricultural habitats in South Dakota but did not provide information on associations with particular crops or management systems. Weiss et al. (1990) assessed ground beetle associations with various tillage and cropping systems for spring wheat in the northern Great Plains. Pavuk et al. (1997) found greater carabid activity in corn grown under weedy conditions.

Implicit in Tonhasca's (1993) observations is the concept that determination and characterization of the dominant carabid species present in an assemblage within a given agricultural system is a necessary initial step toward the management of carabids as natural pest control agents. Thus, our objectives were to characterize the dominant carabid species present in crops and crop rotation sequences commonly used in the northern Great Plains and to determine whether the level of chemical management input to these rotations influenced the composition of carabid assemblages.

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Table 1. Preemergence and postemergence herbicides applied to high-input, managed and low-input plots of corn, soybean, and wheat during 1993 and 1994

Crop	Year	High-input plots		Managed plots		Low-input plots	
		Herbicide	Application rate	Herbicide	Application rate	Herbicide	Application rate
Corn	1993	Alachlor (pre)	7.0 liters/ha	Nicosulfuron (pre)	48.7 ml/ha	—	—
		Cyanazine (pre)	2.3 liters/ha	—	—	—	—
		Bentazon (post)	2.1 liters/ha	Bentazon (post)	2.1 liters/ha	Bentazon (post)	2.1 liters/ha
	1994	Alachlor (pre)	7.0 liters/ha	—	—	—	—
		Cyanazine (pre)	2.3 liters/ha	—	—	—	—
		Bromoxynil (post)	1.8 liters/ha	Bromoxynil (post)	1.8 liters/ha	—	—
Soybean	1993	Alachlor (pre)	7.0 liters/ha	—	—	—	—
		Metribuzin (pre)	0.56 kg/ha	—	—	—	—
		Bentazon (post)	2.1 liters/ha	Bentazon (post)	2.1 liters/ha	Bentazon (post)	2.1 liters/ha
	1994	Flumetsulam + metolachlor (post)	2.9 liters/ha	—	—	—	—
Wheat	1993	MCPA-amine (post)	0.6 liters/ha	MCPA-amine (post)	0.6 liters/ha	—	—
	1994	MCPA-amine (post)	0.6 liters/ha	MCPA-amine (post)	0.6 liters/ha	—	—

Pre, preemergence application; post, postemergence application.

Materials And Methods

Rotation and Input Treatments. Crop rotations with variable input level treatments were established in 1990 on Vienna loam (fine-loamy, mixed Udic Haploboroll) soil at the Eastern South Dakota Soil and Water Research Farm near Brookings, SD. Three replications of crop rotation treatments and 3 input levels were evaluated in a split-plot experimental arrangement such that each crop in the rotation was present each year. Rotations included continuous corn monoculture, a 2-yr corn–soybean rotation, a 2-yr ridge-tilled corn–soybean rotation, and a 4-yr corn–soybean–wheat underseeded with alfalfa–alfalfa rotation. Input level (high-input, managed, low-input) subplot treatments (30.5 m long, 30.5 m wide) were superimposed on the main plot rotation treatments. There were 27 subplots of rotation and input level combinations in each replication, for a total of 81 subplots.

High-input treatments for the rotations included soil test-based fertilizer application for established yield goals (112 kg/ha of 13:33:13 N:P:K starter; 96 and 122 kg/ha actual N sidedressed in 1993 and 1994, respectively). Prophylactic pre- and postemergence herbicide applications were done according to the schedule in Table 1, and prophylactic soil insecticide (dyfonate 7.8 kg [AI]/ha) was made as a planting time application. Tillage consisted of fall moldboard plow–spring disk–spring field cultivator operations. Fertilizer application to managed plots was based on soil tests for 5.33 Mg/ha corn yield goal (53 kg/ha of 13:33:13 N:P:K starter, 67 and 48 kg/ha actual N sidedressed in 1993 and 1994, respectively). Herbicide applications were made at the rates shown in Table 1 when weed seed bank or weed seedling counts indicated potential economic loss from weeds. Managed plots did not receive soil insecticide treatments because corn rootworm beetle counts did not exceed a threshold of 1 beetle per plant during the prior year. Tillage in the managed plots consisted of fall moldboard plow in odd years and fall chisel plow in even years followed by spring disk or field cultivator operations. Low-input plots did not receive fertilizer, insecticide, or herbicide applications (except postemergence bentazon in 1993, Table 1). Tillage consisted of fall chisel plow with spring disk or field cultivation. All corn and soybean plots received two postemergence row cultivations early in the growing season for weed control.

Weed Seed Counts. Relative weediness of subplots associated with each level was assessed from weed seed counts for each rotation and input level combination during 1993 and 1994. Weed seed counts were taken using 6 seed traps (Forcella et al. 1996) placed along a diagonal transect through the center of a subplot. The seed traps were plastic cups 10 cm deep with a 10-cm-diameter opening. Drainage holes were cut in the bottom of the cup and brass screen (0.4-mm mesh openings) matching the inside diameter of the cup was inserted to retain weed seeds. The cup was attached to a wooden stake driven into the soil such that the top rim of the cup was 10–15 cm above the soil surface.

Traps were placed in the subplots in early August and remained in place until crops were harvested. At that time they were repositioned to adjacent crop rows to avoid damage by the harvester's tires and to provide an estimate of seeds dispersed by the harvester. This necessary movement of the traps did not alter their differential seed entrapment capabilities (Forcella et al. 1996). After harvest, all seeds were separated into grass and broadleaf categories and counted.

Pitfall Trapping. Pitfall trapping of Carabidae was conducted in 1993 and 1994, beginning in the 4th yr of the longest rotational crop sequence. One pitfall trap with an opening of $\approx$58 cm^2 was placed in the approximate center of each subplot. To prevent excessive impact on the density of ground beetles, pitfall traps were active for only 48 h at weekly intervals. When not active, the traps were covered with plastic petri plates to prevent undue impact on carabid populations in the plot area and to keep rainfall and soil out of the containers. First-year collections commenced the week of 26 May 1993 and continued through the week of 31 August 1993. Second-year collections started 18 May 1994 and continued through the week of 6 September 1994. Carabids were identified to species and numbers of each species collected during each 48-h exposure period were determined. Nomenclature consistent with that of Bousquet and Larochelle (1993) was used. Voucher specimens have been deposited in the South Dakota State University collection.

Data Analysis. Total numbers of beetles collected, and numbers of dominant species in the collections from corn and soybean were analyzed over rotation and input level using general linear model procedures in SAS (SAS Institute 1989) for a split-plot experimental design. Beetle data were transformed to log $(x+1)$ before analysis. Collections from wheat and alfalfa were analyzed only over input level because these crops appeared only in 1 rotation. Dominant species were considered to be those comprising ≈80% of the total collected (Tonhasca 1993). Dominance indices were calculated as $D_i = N_i / N_T$, where N_i is abundance of the ith species and N_T equals the total numbers of carabids (Tonhasca 1993).

Diversity and species richness over crops, rotations, and input level were compared using 3 indices of diversity the Shannon-Weaver Index (H′, Shannon and Weaver 1949); evenness or relative diversity (J′, Pielou 1966); and the Hierarchical Richness Index (HRI, French 1994). The Shannon-Weaver Index was calculated by the method shown in Zar (1996) as $H' = -\Sigma\ p_i \log p_i$, where p_i is the proportion of the ith species among the total collected. Relative diversity was calculated as $J' = H'/H'_{\max}$, where $H'_{\max}$ is log k and k is the number of species collected. French (1994) proposed the HRI as a measure of diversity that accounts for both species richness and abundance in samples from a community. The HRI was calculated as $\mathrm{HRI} = \Sigma\ (s_i \times i)$, where i is species rank by abundance and s_i is abundance of the ith species.

Weed seed data were not normally distributed as indicated by the Kolmogorov-Smirnov test for normality (Steele and Torrie 1980). Therefore, these data were pooled over rotations for each input level and subjected to the Kruskal-Wallis (1952) 1-way analysis of variance (ANOVA) on ranks.

Results and Discussion

In total, 6,351 carabid beetles were collected during 1993 and 1994 (Table 2). Total numbers of carabids collected from corn varied significantly with rotational system in 1993 ($F = 2.80$; df = 3, 6; $P < 0.05$) and 1994 ($F = 4.81$; df = 3, 6; $P < 0.05$) but did not vary with input level in either year. In soybean, total numbers collected varied significantly with rotational system in 1993 ($F = 2.80$; df = 2, 6; $P < 0.05$) but not in 1994 and varied significantly with input level in 1994 ($F = 4.42$; df = 2, 8; $P = 0.05$). Total numbers of carabids did not vary with input level in wheat or alfalfa.

Table 2. Carabidae collected from pitfall traps during 1993 and 1994 showing total numbers collected for each species, percentage of total, and cumulative percentage of total for dominant species comprising 90% of total collected

Species	Total	% total	Cumulative, %
Cyclotrachelus alternans (Casey)	2,336	36.8	36.8
Poecilus lucublandus Say	1,272	20.0	56.8
Harpalus pensylvanicus DeGeer	673	10.6	67.4
Bembidion quadrimaculatum L.	540	8.5	75.9
Pterostichus permundus Say	197	3.1	79.0
Bembidion rapidum Leconte	190	3.0	82.0
Harpalus compar F.	181	2.9	84.9
Harpalus erythropus Dejean	173	2.7	87.6
Chlaenius laticollis Say	159	2.5	90.1
Agonum placidum Say	129	2.0	—
Brachinus cordicollis Dejean	67	1.1	—
Harpalus eraticus Say	56	*	—
Anisodactylus rusticus Say	47	*	—
Poecilus chalcites Say	43	*	—
Harpalus caliginosus F.	35	*	—
Amara carinata Leconte	27	*	—
Chlaenius sericeus Forster	26	*	—
Scarites subterraneus F.	25	*	—
Elaphropus incurvus Say	25	*	—
Agonum cupripenne Say	24	*	—
Scarites substriatus Say	21	*	—
Stenolophus lecontei (Chaudoir)	19	*	—
Amara obesa Say	17	*	—
Bembidion nitidum Kirby	14	*	—
Loricera pilicornis F.	10	*	—
Notiophilus semistriatus Say	7	*	—
Pterostichus femoralis Kirby	6	*	—
Clivina impressifrons Leconte	5	*	—
Anisodactylus ovularis Casey	5	*	—
Bembidion rupicola Kirby	4	*	—
Calosoma calidum F.	3	*	—
Galerita janus F.	3	*	—
Stenolophus conjunctus Say	2	*	—
Agonum gratiosum Mannerheim	2	*	—
Chlaenius pennsylvanicus Say	2	*	—
Anisodactylus sanctaecrucis F.	1	*	—
Dyschirius globulosus Say	1	*	—
Clivina bipustulata F.	1	*	—
Pterostichus commutabilis Motschulsky	1	*	—
Anisodactylus carbonarius Say	1	*	—
Pterostichus melanarius Illiger	1	*	—

*, Values < 1%.

Weed Seed Production. Grass and broadleaf weed seed produced per square meter are shown in Fig. 1. Analysis of variance on ranks suggested that amounts of grass weed seed produced varied significantly with input level in 1993 ($H = 24.1$, df = 2, $P < 0.0001$) and 1994 ($H = 24.7$, df = 2, $P < 0.0001$). Broadleaf weed seed produced in the plots varied significantly with input level in 1993 ($H = 15.9$, df = 2, $P < 0.0004$) but not in 1994 ($H = 5.9$, df = 2, $P = 0.0524$). Numbers of weed seed trapped per m^2 under low and managed inputs were significantly different than numbers trapped in the high-input plots. Grass seed production (primarily yellow foxtail, *Setaria glauca* L.) was generally greater than broadleaf seed production at all input levels.

Dominant Species. Four carabid species—*Cyclotrachelus alternans* (Casey), *Poecilus* (=*Pterostichus,* in part) *lucublandus* Say, *Harpalus pensylvanicus* (DeGeer), and *Bembidion quadrimaculatum* L.—comprised ≈75% of the total collected (Table 2). These, among other species, also were dominant in assemblages studied by Rivard (1966), Tonhasca (1993),

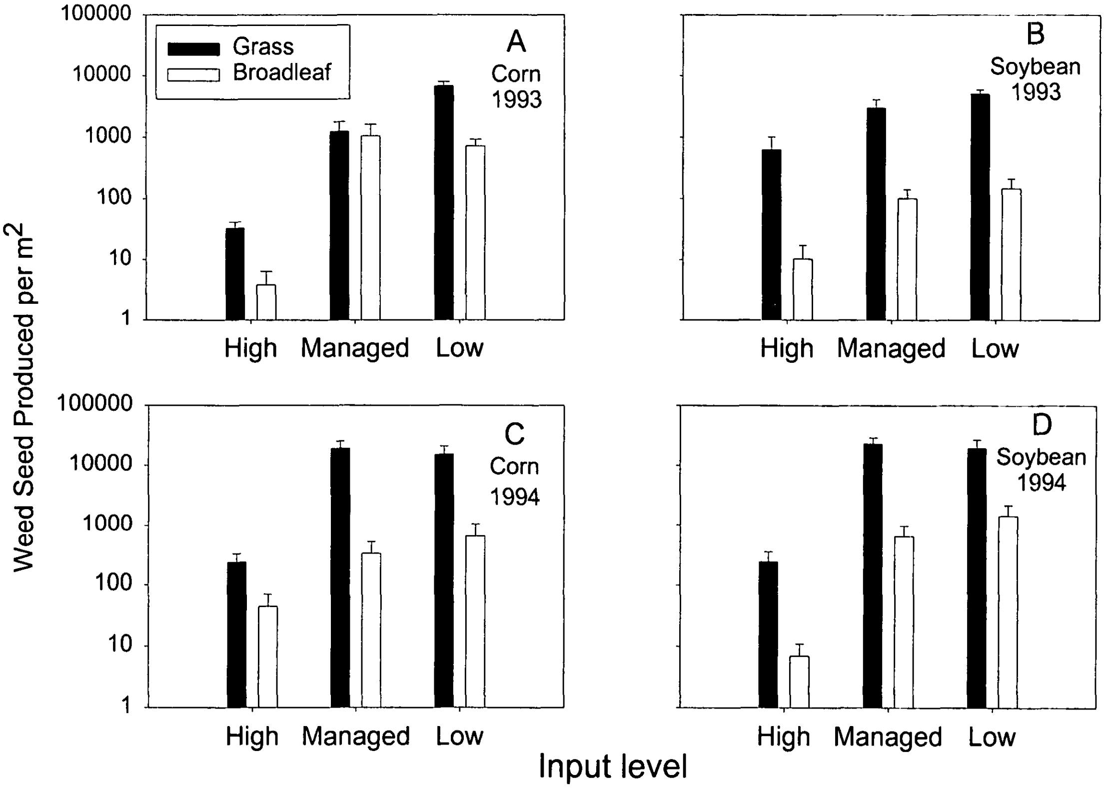

Fig. 1. Influence of management inputs on grass and broadleaf weed seed production pooled over rotations during 1993 and 1994 in corn and soybean plots at Brookings, SD. Error bars represent standard error of the mean.

Cáracamo et al. (1995), and Pavuk et al. (1997). *C. alternans* and *H. pensylvanicus* also were among the 4 most abundant species reported by Kirk (1971) in South Dakota. Weiss et al. (1990) also found significant numbers of *H. pensylvanicus* in a North Dakota study of Carabidae in various tillage and cropping systems. Other species, *Harpalus eraticus* Say, *Amara carinata* Leconte and *P. chalcites* Say, that were dominant species in the study by Kirk (1971) were found in very low numbers (Table 2) in this study. Interestingly, *Cyclotrachelus sodalis* LeConte, which was a dominant species in no-tillage plots in Ohio (Tonhasca 1993), apparently was replaced by *C. alternans* in managed and low-input plots in South Dakota. This is consistent with the geographical distribution of these 2 species as figured by Freitag (1969). Abundance of *C. alternans* varied significantly with input level in corn during 1993 ($F = 10.70$; df = 2, 12; $P < 0.05$) but not in 1994. Numbers of *H. pensylvanicus* varied significantly with input level in corn during both years ($F = 8.09$; df = 2, 12; $P < 0.01$ and $F = 17.76$; df = 2, 12; $P < 0.01$ in 1993 and 1994, respectively) and in soybean ($F = 5.98$; df = 2, 8; $P < 0.05$ and $F = 10.51$; df = 2, 8; $P < 0.01$ in 1993 and 1994, respectively). Numbers of *B. quadrimaculatum* varied significantly with input level in soybean during 1993 ($F = 4.66$; df = 2, 8; $P < 0.05$).

When carabid abundance data were grouped by crop, *C. alternans* was the dominant species in corn and alfalfa (Figs. 2a and 3a) and *P. lucublandus* was dominant in wheat. *P. lucublandus* also was a dominant species found in wheat fields by Doane (1981) and Weiss et al (1990). In soybean plots, 2 dominant species, *C. alternans* and *P. lucublandus*, were trapped in about equal proportions (Figs. 2a and 3a). When data were grouped by rotation over all crops, *C. alternans* and *P. lucublandus* generally were the dominant species, except in continuous corn in 1994 (Figs. 2b and 3b). The relative proportion of *H. pensylvanicus* was highest in the low-input plots (Figs. 2c and 3c), although *C. alternans* remained the dominant species. The higher relative abundance of *H. pensylvanicus* in the low-input plots may be explained in terms of habitat preference for the weedier environment (Fig. 1) in those plots. Shelton and Edwards (1983) found that *Harpalus* spp. feed on seeds of foxtail, a weedy grass species that was particularly abundant in the low-input plots. Larvae of *H. pensylvanicus* also are known to cache seeds of foxtail (Kirk 1972).

Diversity and Species Richness. Diversity as measured by the Shannon-Weaver Index (H') is shown in Table 3 for cumulative data grouped by crop, rotation, and input level. Values of H' were highest for soybean and wheat plots during 1993 and 1994, respectively. Over rotations, H' was highest in plots from the corn-soybean rotation and the continuous corn in 1993 and 1994, respectively. Low-input plots showed consistently higher H' values than did the managed or high-

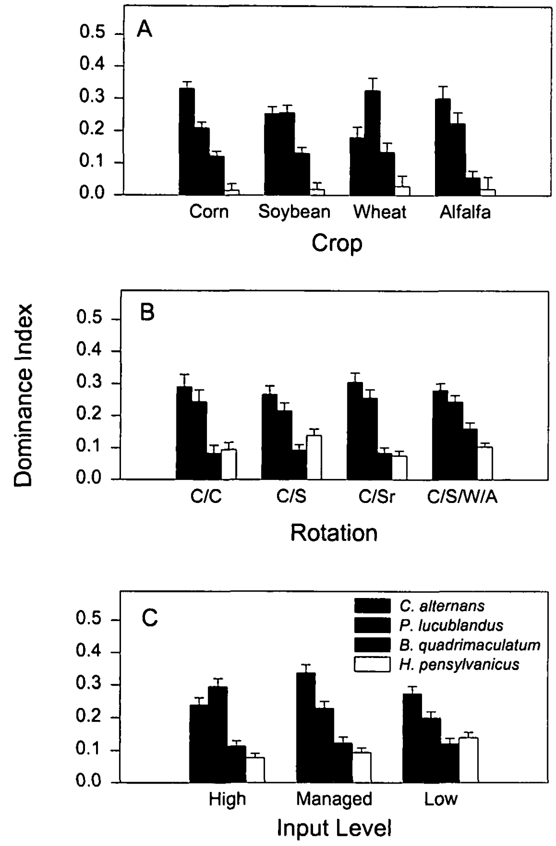

Fig. 2. Dominance indices for four species of Carabidae collected from cropping systems studies in South Dakota during 1993: *Cyclotrachelus alternans* (Casey), *Poecilus lucublandus* Say, *Harpalus pensylvanicus* (DeGeer), and *Bembidion quadrimaculatum* L. Pitfall trapping data were grouped by (A) crop, (B) rotational system, and (C) level of chemical input.

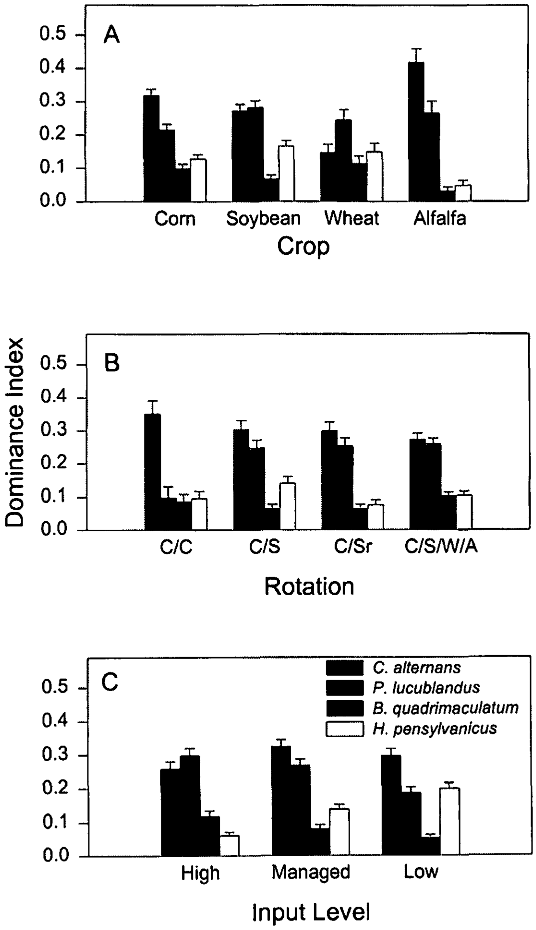

Fig. 3. Dominance indices for four species of Carabidae collected from cropping systems studies in South Dakota during 1994: *Cyclotrachelus alternans* (Casey), *Poecilus lucublandus* Say, *Harpalus pensylvanicus* (DeGeer), and *Bembidion quadrimaculatum* L. Pitfall trapping data were grouped by (A) crop, (B) rotational system, and (C) level of chemical input.

input plots over all crop and rotation combinations. This may be interpreted as an indication that low-input plots, which generally contained more weeds than other input levels (Fig. 1), also supported a greater diversity of carabids. Zar (1996) cautioned that the magnitude of H' is affected by the number of categories (carabid species) that are used in the calculations, as well as the distribution of species abundance. The number of carabid species contributing to the determination of H' varied from 14 in alfalfa during 1993 to 29 in the low-input plots and corn during 1994 (Table 3). More species of carabids were collected from all plots in 1993 than in 1994.

An alternative calculation, J' (relative diversity), expresses H' as a proportion of the maximum possible diversity for a given number of species. The magnitudes of J' were higher for carabids collected from wheat than for all other crops during both years, but were less consistent over rotational systems and input levels. The highest J' values were associated with the corn-soybean rotation in 1993 and continuous corn in 1994 (Table 3). Relative diversity over input levels was greatest in the low-input plots in both years.

Also shown in Table 3 are HRI values that provide an assessment of both species richness and diversity (French 1994). The HRI values were consistently higher in corn and soybean plots than in wheat and alfalfa in both years. The 4-yr rotation showed the highest overall richness and diversity as measured by HRI, as might be expected because this cropping system involves 4 crops. When input levels were compared, the low-input plots had the highest values of HRI (3,120 and 3,896, for 1993 and 1994, respectively). Values of HRI in the managed plots also were relatively high (3,008 and 3,500 for the 2 yr). We attribute these to the weedier environment in the low-input plots and to a lesser extent in the managed plots (Figs. 1, 2c, and 3c) which received less weed control input than did the high-input plots. The high values of HRI

Table 3. Shannon–Weaver Diversity Index and Hierarchical Richness Index for carabid species collected in 1993 and 1994

Source of trap data	Treatment	*n*		*H′*		*J′*		HRI	
		1993	1994	1993	1994	1993	1994	1993	1994
Crop	Corn	23	29	0.865	0.845	0.635	0.577	4384	3870
	Soybean	19	22	0.875	0.750	0.684	0.578	2487	3580
	Wheat	15	20	0.856	0.947	0.728	0.728	1705	892
	Alfalfa	14	20	0.735	0.778	0.678	0.565	1010	931
Rotation	C–C	20	23	0.862	0.897	0.687	0.659	1135	1175
	C–S	19	21	0.913	0.804	0.714	0.608	1961	2003
	C–Cr	21	23	0.846	0.782	0.640	0.575	2324	2275
	C–S–W–A	21	28	0.862	0.847	0.652	0.585	3359	4716
Input Level	High	19	27	0.864	0.842	0.528	0.588	2708	3120
	Managed	21	26	0.830	0.785	0.628	0.555	3008	3500
	Low	23	29	0.906	0.868	0.666	0.594	3120	3896

Data were grouped by crop, rotational sequence, and level of chemical and cultural input. *n*, number of species collected; H′, Shannon–Weaver index; *J′*, Evenness; HRI, Hierarchical Richness index. Rotations: C–C, continuous corn; C–S, corn–soybean rotation; C–Cr, corn–soybean rotation ridge-tilled; C–S–W–A, corn–soybean–wheat underseeded to alfalfa–alfalfa in 4 yr rotation.

for carabid diversity and species richness in the managed plots suggest that reduced chemical inputs to the managed plots encouraged greater abundance and diversity of beneficial carabids than were found in the high-input plots without the loss of yield seen in the low-input plots (Riedell et al. 1997). This result agrees with that of Cárcamo et al. (1995), who found that chemical fertilizer and herbicide inputs associated with intensive conventional agriculture had a negative effect on carabid populations.

The potential of ground beetles as natural control agents for crop pests generally is recognized in the many studies that characterize carabid assemblages associated with various crops (Esau and Peters 1975, Lesiewicz et al. 1983, Barney and Pass 1986) and with tillage or management systems (Tyler and Ellis 1979, Dritschilo and Wanner 1980, House and All 1981, Tonhasca 1993), but management tactics that enhance the value of carabids as natural control agents are not generally available. Thiele (1977) commented that "autecological analysis of the habitat selection of individual species is indispensable for elucidating the reasons underlying the limitation of species to certain habitats." Likewise, development of autecological knowledge of dominant carabid species, such as *P. lucublandus* that was associated with the wheat plots of our study, also is essential if we are to minimize limitations on the abundance of carabids and successfully enhance their value as natural control agents against particular pest insects in agricultural settings.

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