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Ground beetle abundance and community composition in conventional and organic tomato systems of California's Central Valley

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Abstract

Ground beetle abundance and community characteristics were compared in tomato systems under conventional and organic management. Beetles were sampled with pitfall traps over a 10-month period during 1997, in plots that had been under consistent management at the University of California at Davis since 1988. Abundance and species richness were greater in the organic system compared to the conventional system. Six of the 17 species collected were found only in organically-managed plots. However, no differences in species diversity or evenness according to the Shannon and Simpson indices were found. These results were found to be consistent with those of most other studies on ground beetle communities in conventional and organic annual cropping systems. © 1999 Elsevier Science B.V.

Keywords: Ground beetles; Organic agriculture; California

1. Introduction

Organic farming methods are generally considered to be less detrimental than conventional methods to predaceous arthropods, particularly to epigean predators such as ground beetles (Carabidae). Cover crops, manure and compost amendments, and avoidance of pesticides create conditions that may conserve or promote such predators on organic farms. In addition, elevated soil organic matter levels resulting from many years of organic management may enhance the detritus-based food web, resulting in greater predator abundance and/or diversity.

Considerable research has been conducted on the effects of agricultural management, such as tillage, mulching, and pesticide use, on ground beetles because of their role as predators of pests. However, the effects of individual management practices appear to depend upon and interact with many other factors, such as site history, crop type, landscape characteristics, ground beetle community characteristics, and the specific combination of management practices used (Booij and Noorlander, 1992; Cárcamo et al., 1995; Clark et al., 1997). Because of this, generalizations about the effects of particular practices on ground beetles are limited.

Organic production systems may share more ecological characteristics in common with each other than conventional systems because they are limited in the types of practices and inputs that can be used. Organic farms typically use long rotations, tillage, cultivation, cover crops, and manure or compost amendments. Further, synthetic fertilizers and pesticides (insecti-

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cides, herbicides, nematicides, and fungicides) are not used. This combination of factors may constitute a management system, that, when used in different locations and climates has consistent and predictable effects on ground beetle communities. The objectives of this study were to compare ground beetle abundance and community characteristics between tomato systems managed organically and conventionally and to compare these findings to other similar studies to determine if generalizations can be made.

2. Materials and methods

2.1. Study site

This study was conducted in 1997 at the Sustainable Agriculture Farming Systems (SAFS) project at the University of California, Davis, CA (38°32′N, 121°47′W, 18 m elevation). The SAFS project was established in 1988 to study agronomic, biological, and economic aspects of conventional and alternative farming systems in California's Sacramento Valley (Temple et al., 1994). The region has a Mediterranean climate with 400–500 mm of rain falling mostly during the winter months (December–March). Soil at the site is classified as Reiff loam and Yolo silt loam.

Four farming system treatments are represented at the site including four-year rotations under conventional, low-input, and organic management and a conventionally-managed, two-year rotation. The crops include processing tomato (*Lycopersicon lycopersicum* [L.] Karst. ex Farw.), safflower (*Carthamus tinctorius* L.), bean (*Phaseolus vulgaris* L.), corn (*Zea mays* L.), and winter wheat *(Triticum aestivum* L.). Tomato plots, measuring 0.12 ha, from the four-year, conventional and organic farming systems were used in this study. Four replications of each treatment were included for a total of eight plots.

2.2. Tomato management

The conventional system was managed with practices typical of the surrounding area, which included the use of synthetic fertilizers and pesticides (Table 1). Decisions to use pesticides in this treatment were based upon common practices in the area as well as University of California integrated pest management (IPM) guidelines. The organic system was managed according to the regulations of California Certified Organic Farmers (1995), and therefore, used no synthetic chemical pesticides or fertilizers. Tomatoes in both the systems were grown on 1.52 m wide beds and furrow-irrigated. Planting in the conventional system was by direct seeding while the organic system used transplants to allow greater legume cover crop (*Vicia sativa* L.) growth in the spring, thereby increasing nitrogen fixation, and provide some advantage over weeds (Table 1).

The conventional tomato systems received synthetic N fertilizer at about 180 kg N ha^{-1}. Most of this was applied as a side dressing of urea ≈7 weeks after planting. In the organic system, composted poultry manure, applied at 7–9 t ha^{-1} (dry weight), and incorporated cover crop biomass supplied the N.

Weeds were managed in the conventional system with herbicides, cultivation, and hand hoeing. The conventional system received four herbicide applications and three cultivations (Table 1). Cultivation was accomplished using a rolling cultivator and tractor-mounted toolbar with sweeps and knives. Hand hoeing was used later in the season when cultivation was no longer possible or to remove weeds in the crop row which were not eliminated with cultivation. Weeds in the organic system were managed with cultivation and hand hoeing. Greater use of hand hoeing in the organic system was economically justifiable due to the premium prices paid for organically-grown tomatoes.

A single insecticide application was used on Julian day 182 (1 July) in both systems to suppress potato aphid (*Macrosiphum euphorbiae* (Thomas) populations (Table 1). In the conventional system, dimethoate (0.56 kg active ingredient ha^{-1}) was applied, while in the organic system, neem extract (2.80 kg active ingredient ha^{-1}) was used.

2.3. Data collection and analysis

Two pitfall traps were placed near the centers of each of the eight plots for 10, ≈1-week periods from February–November, 1997. Each trap was a plastic cup (10.5 cm diameter, 12 cm depth) with a small amount of soil in the bottom. No killing agent was used. Each trap was installed, with the opening flush to the soil surface, on the top of a bed to avoid flooding due to rain or irrigation. The two traps within each plot were separated from each other by at least 25 m and from the edge of the plot by 10 m.

Table 1
Summary of management operations during 1997 in the conventional and organic tomato systems of the SAFS Project, Davis, CA

Month	Julian days	Conventional system	Organic system
February	32–59	Herbicide applications (2)[a]: glyphosate (0.63 kg a.i. ha^{-1}) paraquat (0.87 kg a.i. ha^{-1})	No management
March	60–90	Herbicide application: napropamide (0.56 kg a.i. ha^{-1}) Surface cultivate and shape beds tomato planting irrigations (2)	Mowing and incorporation of vetch cover crop Application and incorporation of composted poultry manure
April	91–120	Cultivations (2) Hand hoeing and thinning Irrigations (2) Urea fertilizer application	Cultivations (2) Form and shape beds Tomato transplanting Irrigations (3)
May	121–151	Herbicide application: EPTC (2.94 kg a.i. ha^{-1}) Irrigations (3)	Cultivations (3) Handhoeings (2) Irrigations (3)
June	152–181	Cultivation Hand hoeing Irrigations (4)	Cultivation Hand hoeings (2) Irrigations (3)
July	182–212	Insecticide application: Dimethoate (0.56 kg a.i. ha^{-1}) Irrigation Tomato harvest	Neem extract (2.80 kg a.i. ha^{-1}) Insecticide application: Irrigations (2) Tomato harvest
August	213–243	No management	No management
September	244–273	No management	Irrigation Cover crop planting (sorghum-sudangrass/cowpea)
October	274–304	No management	Irrigations (2)
November	305–334	No management	No management

[a] Numbers in parentheses indicate the number of times the management practice was used more than once in a month.

Pitfall traps provide a relative measure of activity and density but cannot be used alone to determine absolute density (Luff, 1975). Nevertheless, they are the most common tools used for monitoring ground beetles because of their cost effectiveness and are considered to provide a reasonably good indication of relative abundance when sampling is conducted over long periods, such as a growing season or year (Baars, 1979; Spence and Niemelä, 1994).

After each trapping period, the contents of the traps were taken to a laboratory, frozen, and pinned. Specimens were identified using Bell (1990); Lindroth (1961–1969) and confirmed by the author with specimens from the Bohart Museum of the University of California at Davis or by Foster Purrington of the Ohio State University. Voucher specimens were deposited in the Bohart Museum. Species names are presented according to Bousquet and Larochelle (1993).

At the beginning of each sampling period, the percent groundcover by vegetation (crop and/or weed) was visually estimated. These values were used to provide possible explanations for observed ground beetle abundance patterns.

Ground beetle abundance and species richness were analyzed graphically and statistically. Data were analyzed for each trapping period and cumulatively throughout the year using Student's *t*-test or, when violations in the assumptions of normality or equal variance were found, the Wilcoxon signed rank test, with α=0.05. Species diversity and evenness were assessed with the Shannon and Simpson indices (Begon et al., 1990, pp. 615–617) using pooled data from the entire year. These values were compared between treatments statistically using Student's *t*-test.

3. Results and discussion

About 300 ground beetle specimens, representing 17 species, were collected from the nearly 70 days of

Table 2
Relative abundance of carabid species collected from tomato cropping systems at the SAFS Project during 1997, Davis, CA

Species	(%) Total
Anisodactylus californicus Dejean	28
Apristus laticollis LeConte	17
Amara aenea (DeGeer)	16
Bradycellus congener (LeConte)	6
Tanystoma maculicolle (Dejean)	5
Stenolophus comma (Fabricius)	5
Harpalus pensylvanicus (DeGeer)	5
Calathus ruficollis Dejean	4
Agonum punctiforme (Say)	3
Pterostichus castanipes (Ménétriés)	2
Anisodactylus binotatus (Fab.)	2
Pterostichus californicus (Dejean)	1
Amara conflata LeConte	1
Tecnophilus croceicollis croceicollis (Ménétriés)	1
Poecilus cursitor LeConte	1
Calosoma peregrinator Guérin-Méneville	<1
Agonum sp.	<1

trapping (Table 2). This is equivalent to $\approx$0.3 beetles trap^{-1} day^{-1}, an extremely low catch rate in comparison to other studies of ground beetles in annual cropping systems that have used similarly sized traps (Table 2). It is impossible to definitively determine the cause of the low trap catches in this study; however, the data suggest that ground beetles may exist at fairly low densities in California's Central Valley, perhaps due to the harsh summer climate (high temperature and low moisture) and land use for intensive agriculture.

Although trap catches were low, differences between treatments in ground beetle abundance and species richness emerged (Fig. 1). Ground beetle abundance early in the year was similar between treatments. Trap catches plummeted in both treatments between the 3rd and 4th trapping periods due to ground preparation activities in late March and early April, prior to tomato planting/transplanting (Fig. 1A). During this period, herbicide applications and surface cultivation were used in the conventional system while disking and bed formation were carried out in the organic system. This resulted in relatively intense soil disturbance in the top 5–15 cm and the elimination of all vegetation on the soil surface in both systems (Fig. 2). Trap catches rebounded in both the systems following these activities, coinciding with the development of the tomato crop canopy (Fig. 1(A) and Fig. 2). However, weekly trap catches were consistently higher in the organic system than the conventional system from the 5th trapping period (April) until the ninth trapping period (September), though differences were statistically significant for only one of these five periods. During the 5–6th trapping periods the tomato canopy in both the systems provided partial groundcover and by the 7–8th periods, nearly complete groundcover. Following tomato harvest, however, the organic system was planted to a biculture of sorghum-sudangrass (*Sorghum arundinaceum* (Desv.) Stapf var. *sudanense* (Stapf) Hitchc.) and cowpea (*Vigna unguiculata* (L.) Walp.), which rapidly covered the ground after planting, while the conventional system remained fallow (Fig. 2). Cumulative catch patterns showed clear and statistically significant differences between treatments with the mean cumulative catch in the organic system more than twice that of the conventional system (Fig. 1(B)).

The ground beetle fauna of both the systems were dominated by *Anisodactylus californicus* Dejean, *Apristus laticollis* LeConte, and *Amara aenea* (DeGeer), which each accounted for over 15% and together comprised 61% of all ground beetles collected. Riddick and Mills (1995) also reported *A. californicus* as a dominant ground beetle species collected from an apple orchard in the delta region of the western Central Valley of California. Although all the three dominant species were trapped in greater numbers from the organic system, no statistically significant differences between treatments were found. All other species were not collected in sufficient numbers for statistical comparisons of their abundance.

The overall patterns in species richness were similar to those observed in ground beetle abundance. No differences between treatments were found during the 1st half of the year and species richness peaked in both systems during the 6th sampling period (Fig. 1C). Following this peak in mid-May, however, greater species richness in the organic system became apparent. The cumulative species richness in the organic system was 11.0$\pm$1.1 compared to 7.5$\pm$0.6 in the conventional system (Fig. 1(D)). Six of the 17 species collected were found only in the organically-managed plots: *Pterostichus californicus* (Dejean), *Amara conflata* LeConte, *Calathus ruficollus* Dejean, *Calosoma peregrinator* Guérin-Méneville, *Harpalus pensylvani-*

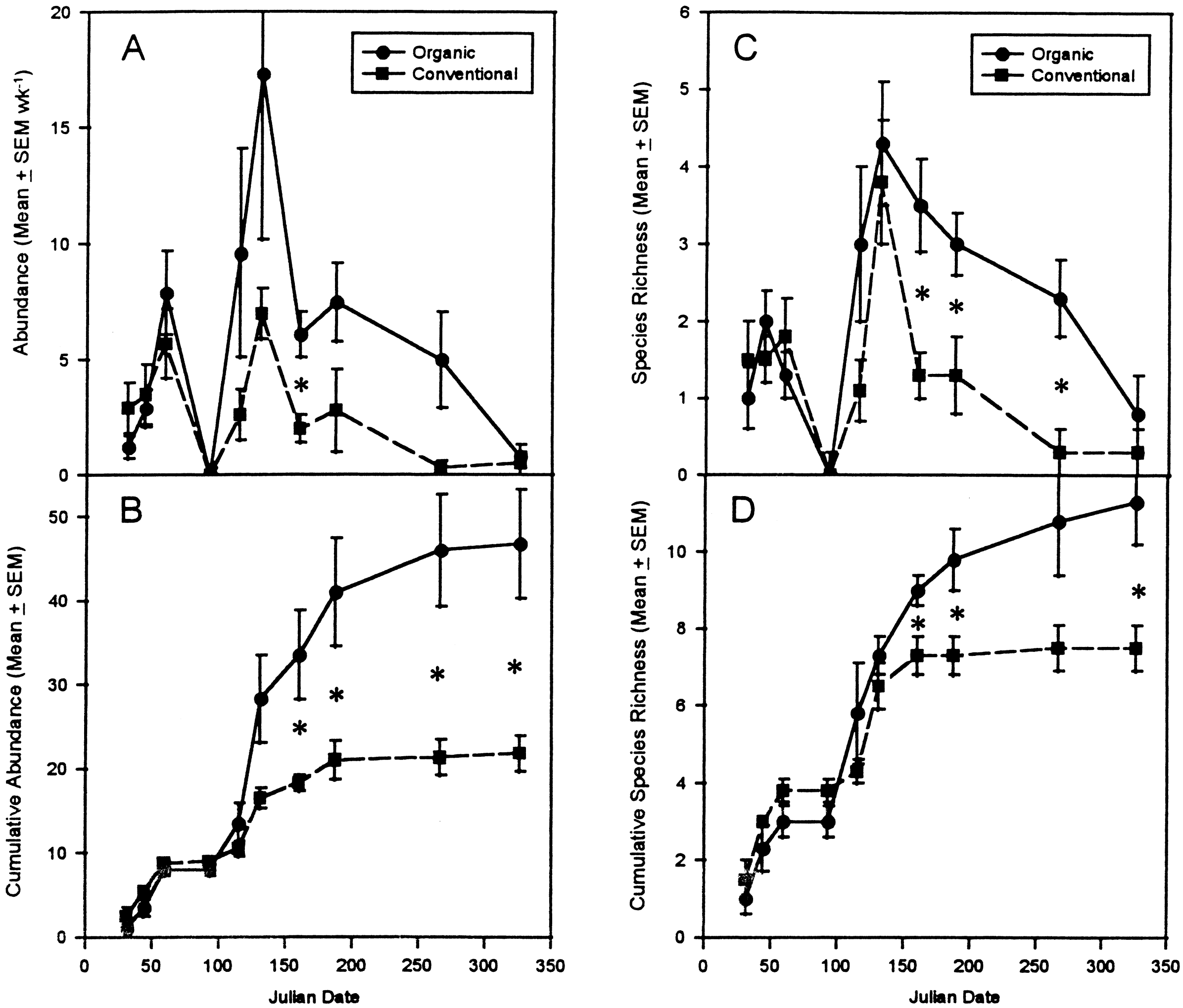

Fig. 1. Ground beetle abundance (A, B) and species richness (C, D) in the organic and conventional tomato systems of the SAFSS Project, 1997. Asterisks indicate significant differences between treatments, Students *t*-test, $P < 0.05$.

cus (DeGeer), *Anisodactylus binotatus* (F.), and *Agonum* sp.; however, no species were collected exclusively from conventional plots (Table 3).

Although, a substantially greater number of ground beetle species was collected from the organic system, no significant difference in species diversity or evenness was found according to the Shannon and Simpson indices (Table 4). This finding is consistent with other studies of ground beetle diversity in organic and conventional annual cropping systems (Table 5). The calculated diversity and evenness values in this study are slightly greater than those reported in Dritschilo and Erwin (1982) for corn fields in the midwestern United States and somewhat lower than those given by Cárcamo et al. (1995) for leguminous field crops in Alberta, Canada. However, both of these studies, as well as that of Hokkanen and Holopainen (1986), showed that, although, ground beetle abundance and species richness increase with the use of organic methods, species diversity does not.

Dritschilo and Erwin (1982) concluded that the use of diversity indices with ground beetles was misleading or redundant because of the insensitivity of these measurements to change resulting from environmental

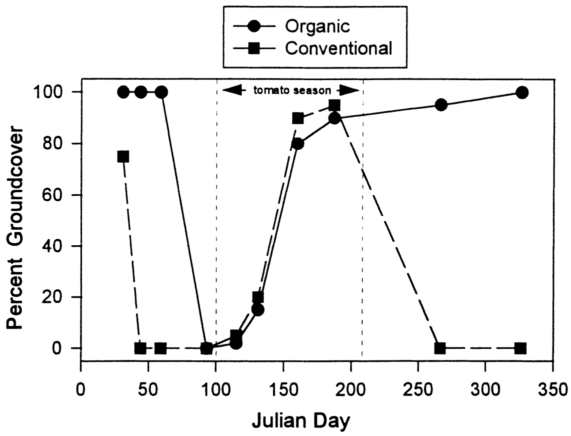

Fig. 2. Percent groundcover in the organic and conventional tomato systems of the SAFS project based on visual estimation. The tomato growing season is indicated by the area within the dotted lines. The cover crops preceeding and following the organic tomato crop were common vetch and a biculture of sorghum-sudangrass and cowpea, respectively.

stress. They suggested that species richness may be a consistent indicator of carabid community change. However, Jarošík (1991) disagreed with these conclusions and stated that the insensitivity of diversity indices results from inadequate sampling duration and that long-term sampling is necessary in order to prevent short-term variation in community structure or meteorological factors from obscuring differences in carabid diversity. Jarošík argued that diversity indices based on long-term pitfall trapping were superior to abundance or species richness as an indicator of change in ground beetle communities. Most comparisons of ground beetle communities between organic and conventional cropping systems, however, provide support for Dritschilo and Erwin's conclusions.

In six of the eight studies on ground beetle communities in organic and conventional annual cropping systems, species richness was greater in the organic systems (Table 5). Ground beetle abundance also tended to be higher under organic management but effects were somewhat less consistent. The study by Armstrong (1995) is the only one to show a negative effect on ground beetle abundance and species richness resulting from organic management. This study had a relatively short duration (sampling was conducted during five, 1 week sessions within a 2-month period) which may account for its inconsistency with other studies. Booij and Noorlander (1992) reported that the organic management had no effect on carabid species richness. In that study, abundance was greater with organic compared to conventional management

Table 3
Average number of carabids collected per trap per day in selected studies of carabid communities in annual cropping systems

Reference	Location	Carabids trap($^{-1}$ d^{-1})
Dritschilo and Wanner (1980)	Iowa and Illinois, USA	1.8
Ferguson and McPherson (1985)	Virginia, USA	1.0
Kromp (1990)	Austria	2.1
Cárcamo (1995)	Alberta, Canada	1.4
Clark et al. (1997)	Michigan, USA	1.0

Table 4
Ground beetle species diversity and evenness in organic and conventional tomato systems of the SAFS Project according to Shannon and Simpson indices

Characteristic	Index	Cropping system		*P*-value[a]
		Organic	Conventional	
Diversity	Shannon (H)	1.87±0.19	1.89±0.19	0.88
	Simpson (D)	6.48±1.51	5.29±0.78	0.50
Evenness	Shannon (H)	0.54±0.04	0.56±0.06	0.77
	Simpson (D)	0.20±0.04	0.21±0.06	0.84

[a] Student *t*-test

Table 5
Response of carabid communities to organic management relative to conventional management in annual cropping systems according to studies from North America and Europe

Reference	Abundance	Richness	Diversity	Evenness
Dritschilo and Wanner (1980)	+	+	0	0
Kromp (1989)	+	+	NA	NA
Kromp (1990)	+	+	NA	NA
Booij and Noorlander (1992)	0,+	0	NA	NA
Armstrong (1995)	0,−	0,−	NA	NA
Cárcamo et al. (1995)	0,+	+	0	0
Pfiffner and Niggli (1996)	+	+	NA	NA

+ – increase; − – decrease; 0 – no effect; NA – not addressed in study.

in five of the six crops evaluated, but crop type had a greater overall effect on abundance and richness than management. In addition, they reported that differences in abundance were due largely to a single species, *Pterostichus melanarius* (Illiger). Cárcamo et al. (1995) found greater ground beetle abundance with organic management only when the European-introduced *P. melanarius* was excluded from the analysis.

None of the three published studies which considered ground beetle diversity found differences in this measurement resulting from organic management. Similarly, the two studies which compared species evenness also reported no effects (Table 5). This investigation, along with the other studies surveyed, indicates that organic management of annual cropping systems results in greater ground beetle abundance and species richness than conventional management, but that diversity and evenness indices do not respond to these community changes, at least when pitfall traps are used as the means of sampling. This means that the rate at which new species are encountered, viewed as a function of the number of specimens collected, is similar in organic and conventional systems. Indeed, this was the case in the present study (Fig. 3); as more species were collected in the traps, so were more individuals, masking community-level changes according to diversity indices.

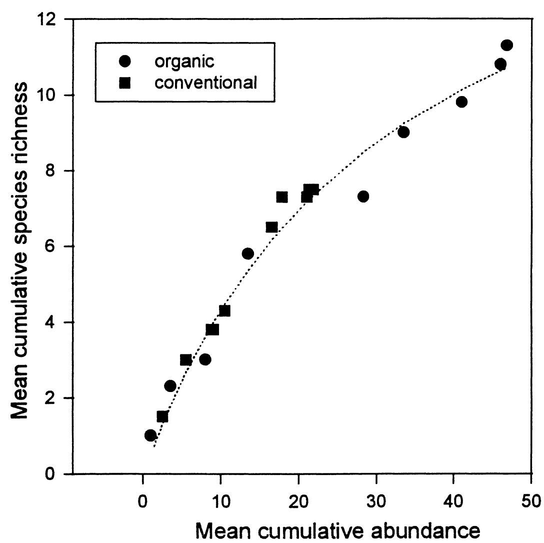

Fig. 3. Relationship between ground beetle cumulative abundance and species richness based on pitfall trap catches from conventional and organic tomato plots at the SAFS Project. The rate at which new species are encountered (richness), measured as a function of the number of specimens collected (abundance), is similar between the two treatments.

4. Conclusions

Ground beetle abundance and species richness were greater in the tomato system under organic management compared to that under conventional management. However, as previous studies have shown, diversity and evenness indices did not respond to these changes in the ground beetle community. The differences observed in ground beetle abundance and species richness likely result from a combination of interacting factors rather than any particular difference in management. The single insecticide application did not appear to have a profound effect on either abundance or richness as similar treatment differences in both of these measurements were apparent prior to and long after this event. Instead, the presence of vegetative groundcover throughout most of the year, but particularly in late summer, was probably important in influencing ground beetles. In addition, other published research from the SAFS site has shown that the detritus-based food web is enhanced in the organic system (Scow et al., 1994; Ferris et al., 1996; Gunapala and Scow, 1998), suggesting that this fundamental ecosystem-level change is now manifested in epigean predators such as ground beetles.

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