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Source: Florida Entomologist, 103(2) : 151-159

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.103.0201

Research

Impact of years in bahiagrass and cultivation techniques in organic vegetable production on epigeal arthropod populations

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Abstract

Plantings of perennial grasses have been shown to be an effective means to enhance soil qualities for organic production. Similarly, tillage methods can significantly impact production in organic crop production systems. We have previously examined direct effects of these practices on crop yields, profitability, and soil quality for rotations of organic vegetables in a 4-yr study in northern Florida, but less is known about the effects of these treatments on arthropods. We report here on experiments that used large fields of Argentine bahiagrass, *Paspalum notatum* Flügge (Poaceae) 'Tifton 9,' converted to seasonal vegetable rotations of oat/rye, bush beans, soybeans, and broccoli in a nested design using 4 levels (yr) of continuous bahiagrass production prior to vegetable rotations and 2 tillage methods (conventional and strip tillage). During the fourth yr of the study, we conducted pitfall trapping on a subset of plots involving all 8 treatments (4 bahiagrass treatments and 2 tillage treatments) to examine effects on epigeal arthropods. Over 10,000 organisms and 48 species were identified with 36 arthropod species comprising greater than 97% of the collected specimens. Fields with increasing yr in bahiagrass significantly increased the number of carabid beetles, whereas there was a decline in total herbivores. Tillage treatments impacted arthropod abundance with a noted decline in total carabids collected in strip tilled plots. Pest management implications of these treatments are discussed.

Key Words: Carabidae; perennial grasses; rotations; pitfall traps; tillage

Resumen

Las plantaciones de pastos perennes han demostrado ser un medio efectivo para mejorar las cualidades del suelo para la producción orgánica. De manera similar, los métodos de labranza pueden impactar significativamente la producción en los sistemas de producción de cultivos orgánicos. Hemos examinado previamente los efectos directos de estas prácticas sobre los rendimientos de los cultivos, la rentabilidad y la calidad del suelo para las rotaciones de vegetales orgánicos en un estudio de 4 años en el norte de la Florida, pero se sabe poco sobre los efectos de estos tratamientos sobre los artrópodos. Presentamos aquí los experimentos que utilizaron grandes campos de pasto de Bahía argentina, *Paspalum notatum* Flügge (Poaceae) Tifton 9, convertidos en rotaciones vegetales estacionales de avena/centeno, frijoles, soya y brócoli en un diseño anidado con 4 niveles (año) de producción continua de pasto de bahía antes de las rotaciones de vegetales y 2 métodos de labranza (labranza convencional y en franjas). Durante el cuarto año del estudio, realizamos trampas de caída en un subconjunto de parcelas que involucraban los 8 tratamientos (4 tratamientos del pasto bahía y 2 tratamientos de labranza) para examinar los efectos sobre los artrópodos epigéneos. Se identificaron más de 10,000 organismos y 48 especies con 36 especies de artrópodos que sumaron más del 97% de los especímenes recolectados. Los campos con años crecientes en pasto de bahia aumentaron significativamente el número de escarabajos carabidos, mientras que hubo una disminución en el total de herbívoros. Los tratamientos de labranza impactaron la abundancia de artrópodos con una disminución notable en el total de los carabidos recolectados en parcelas labradas en franjas. Se discuten las implicaciones del manejo de plagas en estos tratamientos.

Palabras Claves: Carabidae; hierbas perennes; rotaciones; trampas de caída; labranza

Limitations to agricultural production in the Southern Coastal Plain include infertile, compacted soils and soil erosion (West et al. 1997; Endale et al. 2014; Khalilian et al. 2017). High rainfall and temperatures also result in increased pest and disease pressures. Crop rotation is an effective method to mitigate some of these problems, and is an important agricultural practice that provides many bio-based functions (Dogliotti et al. 2004; Kuepper & Gegner 2004; Carter et al. 2009). Perennial grasses, mainly bahiagrass *Paspalum notatum* Flügge (Poaceae), have been found to impart a number of advantages when used as a rotational crop, although historically they have been considered an invasive weed species (Marois et al. 2002; Katsvairo et al. 2006). Among the merits of bahiagrass is the ability of their

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roots to penetrate the natural zone of soil compaction to about 1 m (Elkins et al. 1977); 15 to 40 cm is the common depth of compaction for most farmland in the Southeast (Kashirad et al. 1967; Khalilian et al. 2017). Bahiagrass has been reported to increase rooting depth, root area, and biomass of subsequent crops. In addition, water in the soil profile is conserved and rooting depth of row crops may be up to 10 times deeper following bahiagrass sod-based rotation than conventional cropping systems (Elkins et al. 1977). This could result in as little as one-tenth the current water requirements for irrigation and promote more sustainable crop production (Elkins et al. 1977; Katsvairo et al. 2007).

Strip tillage is particularly effective when used in concert with sod-based rotation. Strip tillage minimally impacts soil, because the soil is tilled only in each row where planting directly occurs. This tillage method maximizes macroporosity and carbon storage, and minimizes erosion (Peigne et al. 2007) while still maintaining the integrity of adjacent soils. Moreover, strip tillage works successfully with a wide variety of crops, whereas crops planted in these systems exhibit significantly higher yields, improved crop quality and plant growth, reduced pesticide use, and higher profits (Wiatrak et al. 2004a, b, 2006).

Despite the acceptance of these more sustainable practices in conventional production, only limited research has been conducted under organic certification (Crowder et al. 2010; Sandhu et al. 2010; Smukler et al. 2010), particularly in the Southern Coastal Plain. Typical off-farm inputs used in conventional, non-organically certified production (such as nutrient supply and pest suppression) must be replaced by mechanisms derived from ecosystem structure and function. These processes include internal nutrient fixation and recycling, enhanced soil microbial populations, and biological pest suppression (such as breaking insect, nematode, weed, and pathogen life cycles), while increasing long-term land productivity (Poveda et al. 2006; Crowder et al. 2010).

Our current research in northern Florida has focused on the effects of bahiagrass sod-rotations and strip tillage on vegetable production in organic crop production systems. We have found that nitrogen and phosphorus soil quality increased (Bliss et al. 2016) where previous bahiagrass rotation is practiced; this has led to increased yields and profitability of vegetable crops (Ahmadiana et al. 2016; Bliss et al. 2016). Grasses also may restore soil biological functions (Carter et al. 2009). We also examined the effects of bahiagrass sod-rotations and strip tillage on soil nematodes and documented that many genera of soil nematodes, particularly root knot and reniform nematodes, significantly decreased with increasing yr in bahiagrass production (Andersen et al. 2016).

Epigeal arthropods comprise the bulk of herbivore, predator, and decomposer species in soil and litter ecosystems (Greenstone 2016). Many of these species are important weed seed and pest predators in agricultural systems (Kromp 1999; Holland and Reynolds 2003; Westerman et al. 2008). Carabid beetles (Coleoptera: Carabidae) are diverse, polyphagous ground dwelling insects that comprise the largest single taxonomic group of epigeal arthropods and often are used as indicator species of diversity, ecosystem functioning, and environmental quality (Leslie et al. 2007; Kotze et al. 2011). Other arthropod groups such as rove beetles (Coleoptera: Staphylinidae), spiders, and ants also are natural enemies of many insect pest species that also have been suggested as bioindicator species (Obrist & Duelli 1996; Clark & Samways 1997; Hummel et al. 2002). We report here on part of a larger study investigating the impacts of bahiagrass sod-rotation and strip tillage on soil nutrients and subsequent crop yields where we examined the effects of these 2 cultural practices on the diverse array of epigeal arthropods found in seasonal rotations of vegetables grown organically in northern Florida.

Materials and Methods

An agricultural field planted with bahiagrass in 2009 was used in this study and located at the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS), North Florida Research and Education Center in Quincy, Florida, USA, at 30.5427833°N, 84.5956833°W. The field was divided into 8 blocks measuring 24.4 m wide × 47.5 m long. Each block was then subdivided into 4 plots (24.4 m wide × 7.3 m long with 6.1 m borders). Each yr, 1 bahiagrass plot per block was randomly selected and brought into vegetable production so that in 2013 (when pitfall sampling began) plots of 0, 1, 2, and 3 yr of continuous bahiagrass production existed within each block. Plots were further divided into 2 subplots 9.1 m long × 7.3 m wide with a 6.1 m border for different tillage treatments.

Cultural practices were based on those used by organic farmers in northern Florida, and specific details are described by Bliss et al. (2016). We note that organic farmers typically use different agronomic practices for cash crops and cover crops. Each winter, beginning in 2011, one-fourth of each bahiagrass plot was randomly selected and converted to a cover crop rotation of oats (*Avena sativa* L.; Poaceae) cv. 'Horizon 270' and rye (*Secale cereale* L.; Poaceae) cv. 'Horizon 401.' In the spring, the cash crop consisted of bush beans (*Phaseolus vulgaris* L.; Fabaceae) cv. 'Valentino' whereas the summer cover crop was soybeans (*Glycine max* (L.) Merrill; Fabaceae) cv. 'Hinson Long Juvenile.' Broccoli (*Brassica oleracea* L.; Brassicaceae) cv. 'Major' was used as the cash crop in the fall. Plots that were already in this rotation remained in this rotation. Bush beans and broccoli were the cash crops of interest whereas oats/rye and soybeans served as cover crops to enhance soil characteristics; cultural methodology reflected usage of the crop. Bush beans and broccoli were planted in 8 rows (7.3 m wide × 0.9 m apart) in each subplot with a spacing of 15 cm for bush beans and 23 cm for broccoli.

For cash crops, Organic Nature Safe (Darling Ingredients, Inc., Irving, Texas, USA) (8-5-5) was applied at 135 kg nitrogen per ha before final tillage (within 3 wk of planting). Conventional tillage required that the total sub-plot be tilled with a rotovator. Strip tillage sub-plots used a strip implement (Kelley Manufacturing Company, Tifton, Georgia, USA) leaving the remaining soil between rows undisturbed. Two wk after planting, bush beans and broccoli were fertilized with organically certified sodium nitrate (16-0-0) at a rate of 34 kg nitrogen per ha. After harvest, bush bean and broccoli plant residue was mowed to allow planting of the oats/rye and soybeans. Seeding rates for cover crops was 70 kg per ha for oats plus 50 kg per ha for rye; soybeans were seeded at 112 kg per ha. Fertilization and tillage were used only for cash crops, because the purpose of cover crops was to increase soil carbon without the expense required to maximize yields for cash crops. Similar to most organic growers, pesticides were provided only on an as needed basis. These were provided twice with Aza-Direct (Gowan Co., Yuma, Arizona, USA) being applied to bush beans in Apr (2.37 L per ha; 28 g ai azadirachtin per ha) and Entrust (147 mL per ha; 35 g ai spinosad per ha; Dow AgroSciences Canada, Inc., Calgary, Alberta, Canada) applied to broccoli in Sep (Table 1). Planting dates were late Mar to early Apr (bush beans), Jun (soybeans), Sep (broccoli), and Dec to early Jan (oats and rye).

Pitfall trapping was conducted throughout 2013 at times when agricultural activity was minimal, but dates were chosen to bracket significant production events (Table 1). Sixteen paired sub-plots were randomly selected (pairing tillage methods) and were sampled multiple times within each rotation. Four pitfall traps were used in each sub-plot per sampling date (64 traps total per date). Collections were completed on 15 and 19 Feb; 3 and 24 May; 11 Jun; 5, 19, and 26 Aug;

Table 1. Significant events in study plots of organic vegetable production during 2013.

Date	Event
9 Jan	Planted rye and oats
25 Jan	Irrigated
15 Feb	Pitfall sample 1
19 Feb	Pitfall sample 2
4–8 Mar	Tilled by treatment
8 Mar	Fertilized 135 kg N ha^{-1}, poultry litter (8-8-8)
1 Apr	Tilled by treatment
1, 4 Apr	Planted bush beans
4 Apr	Chiselvate between rows in ST plots (weed control)
22 Apr	Fertilized with 34 kg N ha^{-1}, sodium nitrate
23 Apr	Applied Aza-Direct insecticide, 2.37 L ha^{-1}
3 May	Pitfall sample 3
13, 20, 24 May	Irrigated
24 May	Pitfall sample 4
29 May – 7 Jun	Harvested bush beans
11 Jun	Pitfall sample 5
12 Jun	Mowed for soybean preparation
25 Jun	Planted soybeans
5 Aug	Pitfall sample 6
19 Aug	Pitfall sample 7
26 Aug	Pitfall sample 8
29, 30 Aug	Mowed for broccoli preparation
4 Sep	Strip tilled
5, 9 Sep	Conventional tilled
11 Sep	Irrigated
13 Sep	Strip tilled
17 Sep	Fertilized 135 kg. N ha^{-1}, poultry litter (8-8-8)
18 Sep	Irrigated
18 Sep	Transplanted broccoli seedlings
19 Sep	Irrigated
20 Sep	Applied Champ fungicide, 1.13 kg ha^{-1}
30 Sep	Applied Entrust 147 mL ha^{-1}
1 Oct	Fertilized 34 kg N ha^{-1}, sodium nitrate
2 Oct	Irrigated
8 Oct	Chiselvate between rows in strip tilled plots (weed control)
8 Oct	Pitfall sample 9

and 8 Oct. The requirement of using a certified organic preservative (see composition later in this section) in the traps prohibited trapping for longer than a wk due to decomposition of captured organisms. Pitfall traps were centered in the fourth or fifth row of each sub-plot and placed 1.8 m apart. Traps were placed at the same location for each collection period.

Ground surface pitfall traps were constructed as follows: the center of a 17.8 cm brown plastic dinner plate was cut out such that a 455 mL Solo cup (Solo Cup Co., Lake Forest, Illinois, USA) would nest in the hole with the top of the cup resting flush with the bottom of the inverted plate. Fine soil was glued to the exposed plate surface to help camouflage the pitfall trap and roughen the plastic surface. The unit was buried in the soil such that the top of the pitfall trap was approximately even with the surface of the ground. A 20.3 cm diam × 2.5 cm high metal wire mesh (12 × 25 mm) ring was placed over the top of each pitfall trap. A second brown plastic plate (25.4 cm diam) was placed atop the metal ring. This plate was secured with soil and served as a protective cover for the pitfall trap beneath. The design helped prevent irrigation and rain water from entering and flooding pitfall traps, and also prevented capture of frogs, shrews, and other small vertebrates. All trap cups were half-filled with an organically certified killing agent consisting of 50:50 Safer Soap (Woodstream Corp., Lancaster, Pennsylvania, USA) and a saturated salt water solution. Unfortunately, this formulation precluded the evaluation of collembolan species and some lepidopterans that became too decomposed to identify. Pitfall traps were emptied and reset after each 4-d sampling date. Samples were cleaned, sorted, and then stored in glass vials containing 95% ethanol solution and later identified in the laboratory.

STATISTICAL ANALYSIS

Most organisms were identified to species, although in some cases only to genus. In a few cases, degradation of specimens in pitfalls only allowed identification to higher taxonomic levels. Data were sorted and analyzed separately by crop rotation (oats/rye, bush bean, soybean, broccoli). Homogeneity of variance was examined by Barlett's test (SAS 2009), and about one-third of the species exhibited heterogeneity of variance. Thus, analyses were performed nonparametrically using Friedman's test. With this procedure, trap catches for each species within a rotation were ranked. Larger taxonomic groups (family, order) and trophic level (predators, omnivores, herbivores) also were analyzed in a similar fashion. In the case of trophic level, species were grouped by the predominant method by feeding behavior (herbivorous, predacious, omnivorous). Nonparametric analyses were completed using SAS (2009). Differences were considered significant at $P \leq 0.05$. All voucher specimens were deposited in the insect collection at North Florida Research and Education Center-Quincy in Quincy, Florida, USA.

Results

A total of 10,192 specimens belonging to 48 taxonomic groups (most identified to species) were collected from the pitfall traps (Table 2). For the more common groups (individuals collected > 5), 33 of the 34 species were arthropods with the exception of slugs (Soleolifera; 236 specimens). The most commonly collected species of arthropods were: *Gryllus pennsylanicus* Burmeister (Orthopera: Grillidae) (2,497 individuals), *Solenopsis* (Hymenoptera: Myrmicinae) (2,177 individuals), *Blattella asahinai* Mizukobo (Blattodea: Ectobiidae) (1,184 individuals), *Forficula auricularia* L. (Demaptera: Forficulidae) (859 individuals), and *Heteroderes amplicollis* Gyllenhal (Coleoptera: Elateridae) (724 individuals). Species diversity was highest for Coleoptera with 11 species being collected, including 5 species of carabid beetles. Other common predatory beetles collected included Staphylinids. Herbivorous beetles in collections included *H. amplicollis*, *Phyllophaga latifrons* LeConte (Coleoptera: Scarabaeidae), *Sitophilus* (Coleoptera: Curculionidae), *Lobiopa insularis* Castelnau (Coleoptera: Nitidulidae), and another unidentified species of sap beetle (Nitidulidae).

Pit fall trap collections varied greatly with time of yr. However, we did not compare arthropod abundance in crops between seasons in the experimental design because it would be impossible to separate effects of season from those of the crop host, which also varied seasonally. Our analyses were sorted by crop-season because most arthropod species have seasonal fluctuations. Cultural practices applied to cash crops also were different than that of cover crops, including applications of organic insecticide during each cash crop rotation that were applied on an as needed basis. However, we do note that, in general, insect abundance (particularly herbivores) was lower in cold weather mo when oats/rye and broccoli were the crops available to arthropods (Table 2). Only 5 of the 22 species categorized as herbivorous or omnivorous were captured during both cold weather rotations, whereas 8 of the 12 predator/parasitoid species were captured during all crop rotations.

Table 2. Mean(± SE) abundance per 10 pitfall traps for common (total caught > 5) arthropods sorted by crop species (tillage methods combined).

Species	Order	Mean abundance per 10 traps			
		Oats/rye	Bush beans	Soybean	Broccoli
		Predators			
Platynus decentis	Coleoptera	3.13 ± 0.53	4.38 ± 0.50	0.78 ± 0.38	2.97 ± 0.66
Harpalus pennsylvanicus	Coleoptera	0.16 ± 0.16	2.35 ± 0.39	0.94 ± 0.25	1.41 ± 0.44
Scarites subterraneus	Coleoptera	0.47 ± 0.22	1.41 ± 0.39	1.30 ± 0.36	0.94 ± 0.37
Galertia bicolor	Coleoptera	0	0.99 ± 0.28	0.05 ± 0.05	0
Tetracha floridana	Coleoptera	0	0	0.78 ± 0.49	0.31 ± 0.22
Staphylinidae spp.	Coleoptera	1.73 ± 0.51	1.37 ± 0.34	0.31 ± 0.22	0.78 ± 0.40
Scolopendra spp.	Scolependra	0.71 ± 0.25	0.89 ± 0.26	0.26 ± 0.14	0
Trachelas tranquillus	Arachnida	7.19 ± 0.86	6.77 ± 0.72	9.58 ± 0.75	1.41 ± 0.50
Trochosa terricola	Arachnida	2.58 ± 0.45	2.50 ± 0.42	13.1 ± 1.1	2.82 ± 0.61
Dasymutilla occidentalis	Hymenoptera	0	1.46 ± 0.59	0	0.79 ± 0.34
Solenopsis spp.	Hymenoptera	15.6 ± 4.1	49.0 ± 4.55	18.3 ± 2.65	107 ± 11.9
Culicoides spp.	Diptera	0	5.57 ± 0.92	0.05 ± 0.05	0.48 ± 0.48
		Omnivores or mixed			
Arion ater	Mollusca: Gastropod	9.29 ± 1.33	3.00 ± 0.49	2.83 ± 0.62	0
Blattella asahinai	Blattodea	0	0.47 ± 0.17	60.1 ± 6.03	0.78 ± 0.34
Scapteriscus abbreviates	Orthoptera	0	0	0.85 ± 0.22	0
Scapteriscus borellii	Orthoptera	0.31 ± 0.15	1.68 ± 0.31	1.22 ± 0.28	5.23 ± 0.96
Gryllus pennsylvanicus	Orthoptera	0.16 ± 0.11	11.8 ± 1.5	113 ± 65	10.9 ± 1.7
Forficula auricularia	Dermaptera	0.31 ± 0.15	9.69 ± 1.03	31.2 ± 2.2	10.9 ± 1.9
Acarina	Acarina	0	3.63 ± 0.26	0	0
Drosophila	Diptera	0	0.36 ± 0.15	0.02 ± 0.01	0
Musca domestica	Diptera	0	2.40 ± 0.44	0.68 ± 0.22	0
Syrphid fly spp.	Diptera	0	0.47 ± 0.17	0.31 ± 0.13	0
Miridae	Hemiptera	0.39 ± 0.23	0.21 ± 0.10	0.21 ± 0.13	0
		Herbivores			
Spodoptera frugiperda	Lepidoptera	0	0.26 ± 0.11	0.94 ± 0.64	0
Heteroderes amplicollis	Coleoptera	0	2.29 ± 0.40	34.0 ± 4.4	4.38 ± 0.94
Nitidulidae spp.	Coleoptera	0	26.2 ± 4.4	0.26 ± 0.12	0
Lobiopa insularis	Coleoptera	0	1.41 ± 0.45	0	0
Phyllophaga latifrons	Coleoptera	0	0.36 ± 0.15	0	0.94 ± 0.79
Sitophilus spp.	Coleoptera	0	0.58 ± 0.18	0.05 ± 0.05	0.78 ± 0.33
Euschistus servus	Hemiptera	0	1.63 ± 0.30	0.10 ± 0.10	0
Pangaeus bilineatus	Heteroptera	0.08 ± 0.08	2.92 ± 0.50	0.05 ± 0.05	0.63 ± 0.31
Lepidoptera	Lepidoptera	0.16 ± 0.16	0.47 ± 0.27	0.31 ± 0.31	0.94 ± 0.37
Pyrrharctia isabella	Lepidoptera	0	0.36 ± 0.14	0	0
Dichromorpha viridis	Orthoptera	0	0.11 ± 0.08	1.69 ± 0.33	0.63 ± 0.31
Microcentrum rhombifolium	Orthoptera	0	0	0.42 ± 0.16	0
Prosapia bicincta	Hemiptera	0	0.21 ± 0.10	0.10 ± 0.07	0

Nearly half (44%) of the common species (n > 5 total individuals captured) were affected by the number of yr in continual bahiagrass or tillage treatment during at least 1 of the crop rotations (Tables 3–5). Effects varied with time of yr and crop. Predatory beetle species, particularly carabids, most often were significantly increased by increasing yr in bahiagrass production (Table 3). *Platynus decentis* Say (Coleoptera: Carabidae) abundance also increased significantly with increasing continuous yr in bahiagrass and conventional tillage systems throughout the winter with oats/rye rotation. The carabid *Harpalus pennsylvanicus* (Coleoptera: Carabidae) similarly showed significantly higher trap catches with increasing yr in bahiagrass with broccoli. Another carabid species, *Scarites subterraneus* (Coleoptera: Carabidae), showed significantly increased trap catches in strip tillage plots in winter (oats/rye rotation). Trap catches of *Galertia bicolor* (Coleoptera: Carabidae) significantly increased with yr in bahiagrass production in the bush bean rotation, and catches of *Tetracha floridana* (Coleoptera: Carabidae) significantly increased in plots with conventional tillage compared with strip tillage in soybeans. In contrast, the wolf spider, *Trochosa tericola* (Thorell) (Araneae: Lycosidae), showed significantly decreased captures with number of yr in continuous bahiagrass production. The most abundant predacious arthropod species (*Solenopsis* spp.) had over 5 times greater capture rate in pitfall traps from strip tilled sub-plots than conventionally tilled plantings of oats and rye.

Effects of bahiagrass treatments on herbivorous or omnivorous species were much less consistent than on predacious species. Sixty-seven percent of the predacious arthropod species were impacted by these treatments at some time during the crop rotations compared with omnivores (40%) and herbivores (30%). Sap feeding beetles (*L. insularis* and other Nitidulidae) increased significantly with increasing yr in bahiagrass with summer bush bean rotation. Asian cockroaches

Table 3. Statistics and mean abundance of predatory epigeal arthropods captured in pitfall traps as a function of yr in bahiagrass and tillage method. Data and statistics are presented only for species and crops that had significant yr in bahiagrass or tillage effects. CT = conventional tillage; ST = strip tillage.

			Tillage		
Species	Crop	Yr in bahiagrass	CT	ST	Statistics
Tetracha floridana (carabid beetle)	Soybean	0	0.33	0.00	Till: $P < 0.040$; df = (3,1,187)
		1	0.00	0.00	
		2	0.29	0.00	
		3	0.00	0.00	
Platynus decentis (carabid beetle)	Oats/rye	0	0.06	0.06	Yr: $P < 0.003$; df = (3,1,123) Till: $P < 0.005$; df = (3,1,123)
		1	0.19	0.19	
		2	0.88	0.13	
		3	0.69	0.31	
Harpalus pennsylvanius (carabid beetle)	Broccoli	0	0.00	0.13	Yr: $P < 0.016$; df = (3,1,59)
		1	0.00	0.00	
		2	0.13	0.13	
		3	0.50	0.25	
Scarites subterrraneus (carabid beetle)	Oats/rye	0	0.00	0.00	Till: $P <0.022$; df = (3,1,123)
		1	0.00	0.00	
		2	0.00	0.25	
		3	0.00	0.13	
Galertia bicolor (carabid beetle)	Bush bean	0	0.00	0.00	Yr: $P < 0.012$; df = (3,1,187)
		1	0.08	0.00	
		2	0.25	0.13	
		3	0.17	0.17	
Staphylinidae spp. (rove beetles)	Broccoli	0	0.00	0.08	Till: $P < 0.042$; df = (3,1,59)
		1	0.08	0.08	
		2	0.42	0.13	
		3	0.13	0.17	
Trachelas tranquilus (wolf spider)	Bush bean	0	0.25	0.42	Yr: $P < 0.035$; df = (3,1,187)
		1	0.25	0.46	
		2	0.21	0.21	
		3	0.08	0.17	
Solenopsis sp.	Oats/rye	0	0.50	5.18	Till: $P < 0.023$; df = (3,1,123)
		1	0.69	1.44	
		2	0.25	2.88	
		3	0.17	0.31	

(*B. asahinai*) were one of the most frequently captured insects, and increased significantly with increasing yr of bahiagrass and strip tillage in the soybean rotation. In contrast, *G. pennsylvanicus* significantly decreased with yr in bahiagrass with bush bean and soybean rotations. Captures of *Musca domestica* L. (Dipera: Muscidae) decreased with yr of bahiagrass in the soybean rotation, whereas captures of *Miridae* increased with increasing yr of continuous bahiagrass production in oats/rye.

When analyzed by higher-level taxonomic or trophic grouping, carabid beetles showed the most consistent treatment effects. The number of continuous yr in bahiagrass production significantly enhanced carabid trap catches in bush beans ($P < 0.036$; df = 3,1,187), broccoli ($P < 0.035$; df = 3,1,59), and oats/rye ($P < 0.001$; df = 3,1,123); only catches in the soybean rotation showed no effects (Fig. 1). Conventional tillage also increased total carabids in cold weather mo compared with strip tillage in oats/rye ($P < 0.043$; df = 3,1,123) and broccoli ($P < 0.40$; df = 3,1, 159; Fig. 1). Total predatory beetles yielded somewhat similar results where significant increases in trap catch was observed with increasing continuous yr of bahiagrass production in bush beans ($P < 0.003$; df = 3,1,187) and oats/rye ($P < 0.002$; df = 3,1,123) rotations. Trap catches also were higher significantly with conventional tillage compared with strip tillage in the broccoli rotation ($P < 0.010$; df = 3,1,59; Fig. 2). Analyses of other groups of predators, total predators, or total predators minus predatory beetles showed no treatment effects. Analyses of total herbivores also showed significant decreases in trap catches in oats/rye ($P < 0.026$; df = 3,1,123) and soybean rotations ($P < 0.040$; df = 3,1,187) with increasing yr in bahiagrass although tillage practice had no significant effects. Analyses of herbivores by taxonomic order showed that Orthoptera decreased with increasing yr in bahiagrass in bush bean ($P < 0.003$; df = [3,1,187]) and soybean rotations ($P < 0.050$; df = [3,1,187]). Total Coleoptera captured were significantly higher in conventionally tilled plots than strip tilled plots in the broccoli rotation ($P < 0.012$; df = [3,1,59]).

Discussion

The most consistent, and perhaps most significant, treatment effects were the number of yr in continuous bahiagrass production increasing captures of all carabid species. Also conventional tillage (as opposed to strip tillage) significantly increased captures of carabid beetles in some crop rotations. The mechanisms of how treatments impact carabids and other species were not addressed in this study. However, this study was conducted as part of a larger one that offers some possi-

Table 4. Herbivorous epigeal arthropods captured in pitfall traps (mean catch per trap) that were significantly affected by treatments. CT = conventional tillage; ST = strip tillage.

Species	Crop	Yr in bahiagrass	Tillage CT	Tillage ST	Statistics (if factorial model is significant at $P < 0.05$)
Lobiopa insularis (Nitidulidae; sap-feeding beetles)	Bush bean	0	0.00	0.00	Yr: $P < 0.004$; df = (3,1,187)
		1	0.04	0.00	
		2	0.13	0.42	
		3	0.13	0.42	
Other Nitidulidae species (sap feeding beetles)	Bush bean	0	1.83	5.33	Yr: $P < 0.047$; df = (3,1,187)
		1	1.04	2.83	
		2	3.38	5.75	
		3	0.33	0.42	
Heteroderes amplicollis	Broccoli	0	0.04	0.42	Till: $P < 0.011$; df = (3,1,59)
		1	0.17	0.25	
		2	0.17	0.38	
		3	0.21	0.21	
Spodoptera frugiperda (armyworm)	Bush bean	0	2.79	3.75	Yr: $P < 0.033$; df = (3,1,187)
		1	6.25	2.29	
		2	4.96	1.17	
		3	4.42	1.50	

ble explanations. The larger study investigated the effects of bahiagrass and tillage on crop yields, nutritional status, and soil parameters (Bliss et al. 2016). Increasing yr in bahiagrass cultivation altered soil nutrition and characteristics resulting in significantly increased crop yields, total nitrogen content of vegetation, and total biomass within the individual plots. Increased vegetative biomass suggested more groundcover for carabids, which has been shown to provide more suitable overwintering refuge for these beetles (MacLeod et al. 2004); however, seasonal effects of grasses may vary with carabid species (Labruyere et al. 2016). Although winters in northern Florida are relatively mild, the strong effects of bahiagrass treatments on carabid trap catch during colder weather (oats/rye and broccoli rotations) are consistent with benefits in overwintering.

We found 7 of the 23 arthropod species categorized as herbivorous or omnivorous were significantly affected by bahiagrass treatment with only 3 species increasing with increased yr of bahiagrass production. Our tangential study (Bliss et al. 2016) previously showed that increasing yr of bahiagrass production resulted in higher plot

Table 5. Omnivorous species (arthropods and others) captured in pitfall traps (mean catch/trap) that were significantly affected by treatments. CT=Conventional tillage; ST=strip tillage.

Species	Crop	Yr in bahiagrass	Tillage CT	Tillage ST	Statistics (if factorial model is significant at $P < 0.05$)
Blatella asahinai (Asian cockroach)	Soybeans	0	2.00	2.17	Yr: $P < 0.001$; df = (3,1,187) Till: $P < 0.001$; df = (3,1,187)
		1	3.75	6.00	
		2	8.92	10.92	
		3	1.88	12.71	
Musca domestica	Soybeans	0	0.13	0.29	Yr: $P < 0.007$; df = (3,1,187)
		1	0.08	0.00	
		2	0.00	0.04	
		3	0.00	0.00	
Gryllus pennsylvanicus (cricket)	Soybeans	0	11.0	17.3	Yr: $P < 0.049$; df = (3,1,187)
		1	14.5	08.9	
		2	14.5	08.0	
		3	09.2	08.0	
Gryllus pennsylvanicus (cricket)	Bush bean	0	2.43	2.13	Yr: $P < 0.003$; df = (3,1,187)
		1	1.21	1.04	
		2	0.46	1.09	
		3	0.41	0.62	
Miridae spp.	Oats/rye	0	0.00	0.00	Yr: $P < 0.029$; df = (3,1,123)
		1	0.00	0.00	
		2	0.06	0.25	
		3	0.00	0.00	

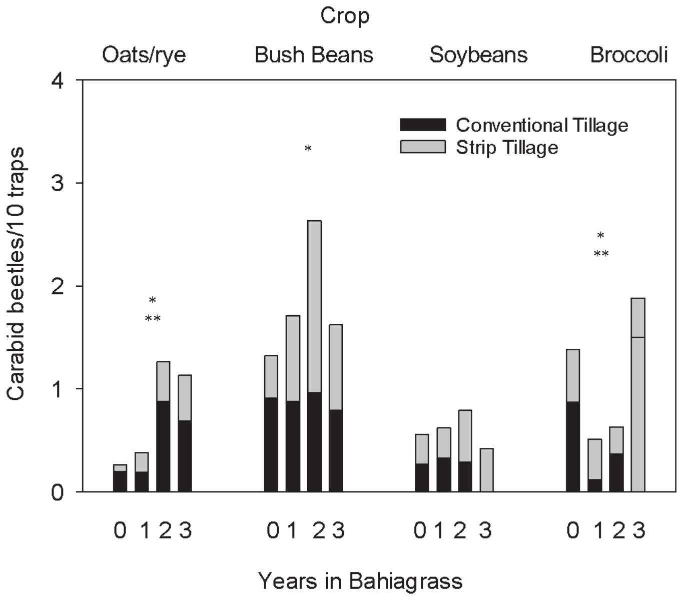

Fig. 1. Mean abundance of total carabid beetles during the 4 crop rotation in 2013. An asterisk (*) denotes significant effects ($P < 0.05$) of yr in bahiagrass. Double asterisks (**) denote significant effects of tillage method.

biomass and higher crop nitrogen content. Thus, it is surprising that these plots with increased plant quality and quantity did not result in increased trap catches of phytophagous insects. Increased predation, particularly by carabids, may have contributed to this lack of increased abundance of herbivores and omnivores. The only herbivorous insects that increased significantly in the summer rotation were 2 species of Nitidulidae. As a rule, sap feeding insects are more likely to be nutrient limited (Brodbeck & Strong 1987). Moreover, members of this family have been shown to respond strongly to changes in diet, as well as having a high reproductive potential (Ellis et al. 2002; Stuhl 2017). Our results with Nitidulidae may parallel those of Holland (1998) and Collins et al. (2002), where aphids (who are often also nutrient limited with a high reproductive potential) may be reduced by carabids and other polyphagous predators until their reproductive capacity outstrips the predator's ability to effectively reduce their numbers.

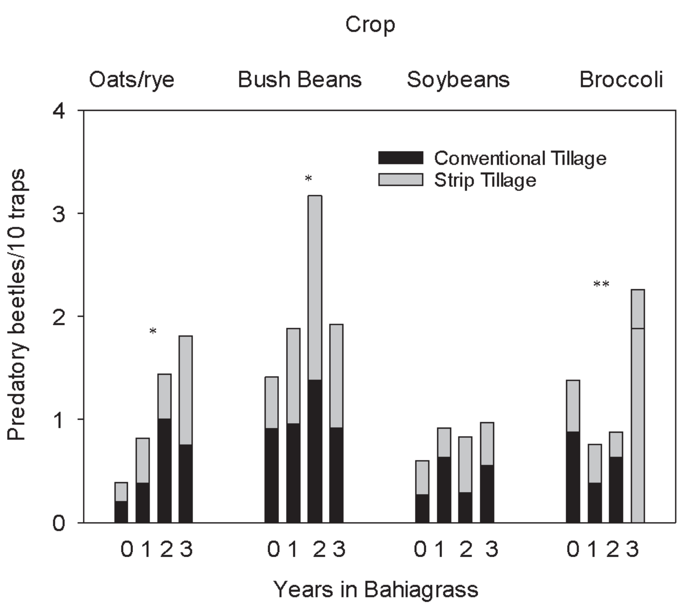

Fig. 2. Mean abundance of total predatory beetles during the 4 crop rotation in 2013. An asterisk (*) denotes significant effects ($P < 0.05$) of yr in bahiagrass. Double asterisks (**) denote significant effects of tillage method.

Effects of tillage practice appeared more variable than the persistence of bahiagrass habitat. Total captures of carabid beetles decreased with strip tillage in cold weather rotations (oats/rye and broccoli). These results contradict those of Kromp (1999) who reviewed numerous studies and concluded reduced tillage benefited carabid populations; however, this review also listed multiple exceptions dependent on study and species. Similarly, Hatten et al. (2007) established differential responses to tillage practice by different carabid species within one study. Holland and Reynolds (2003) documented differential response to identical tillage treatments on a yr-to-yr basis. In our study, trap abundance of the most common predator, *Solenopsis*, was > 5-fold greater in strip tillage than conventional tillage in cold weather (oats/rye rotation), perhaps because ant nests were more susceptible to disturbance by tillage in cold weather, similar to the findings of Landis et al. (2000) and Pereira et al. (2010). We also found 2 of the 23 arthropod species categorized as herbivorous or omnivorous were significantly impacted by tillage treatment.

Cover crops, as well as grasses, have been shown to increase carabid overwintering success (Rivers et al. 2017). We documented the persistence of carabids throughout the yr, particularly when compared with the seasonal nature of other species such as herbivorous insects. Our use of winter cover crops, as well as collecting from plots with previous yr of continuous bahiagrass cultivation, may contribute to those results. Conversely, most non-predacious species investigated in our study showed strong seasonal population fluctuations. Reasons for such fluctuations could be due to normal seasonal fluctuations for individual species or the result of host-specific responses by plant-eating insects to different crops planted throughout the crop rotations. Specifically, seasonal differences in abundance also may have been influenced by host associations with the diversity of weed species within plots. One should note that the study followed a protocol typical for organic production pest control where organic insecticides were applied on an as needed basis. Aza-Direct was applied on 23 Apr while Entrust (spinosad) was applied on 30 Sep. These treatments could have contributed to temporal variation in insect populations. Although identifying mechanisms to explain seasonal variability were not investigated, there was a clear trend regarding feeding type; 67% of all predatory species were found in all rotations, as opposed to 30% of omnivorous species and 15% of herbivorous species.

Carabid beetles provide valuable ecosystem services as pest and seed predators (reviewed by Lövei & Sunderland 1996, and Kromp 1999). The presence of beneficial insects, such as carabids and arachnids, may lengthen periods between pest outbreaks. Interestingly, in the United Kingdom and Europe, "beetle banks" have been created (Thomas et al. 2002; MacLeod et al. 2004), where habitats are managed specifically for the maintenance of carabid populations; most often these are perennial grasses planted and maintained adjacent to or within crops. The efficacy of beetle banks in suppressing pest populations is well documented (Chiverton 1987; Collins et al. 2002). Grassland corridors (Do et al. 2017) and the presence of grassland on crop margins (Thomas et al. 2002) also have been investigated as management tools to encourage the ecological services of carabids.

We believe the value of carabid beetles, and other generalist predators, is enhanced in organic crop production systems where conventional methods of pest control are limited. These organic systems have been shown to maintain generally higher populations of carabids in crops and adjacent habitats than do conventional systems (Purtauf et al. 2005; Lundgren et al. 2006; Caprio et al. 2015), although anomalies exist (Rondon et al. 2013). Organic crop production systems also may enhance carabid emigration from adjacent habitats which may be of great benefit given the relatively low dispersal abilities of many carabid species (Lövei & Sunderland 1996; Do et al. 2017). Our results suggest that a further understanding of how bahiagrass enhances the abundance of carabid populations and the resultant pest management potential of these treatments merit further investigation in organic and conventional crop production systems.

Acknowledgments

We thank Victoria Ospina for technical assistance. Our thanks also to Baron Riddle and Charlie Riddle for collection of data and preliminary statistical analyses. This research was partially funded by grant No. 2010-51106-21866 from the USDA NIFA-Organic Transition Program to P. C. Andersen, R. F. Mizell, III, J. J. Marois, D. L. Wright, and others.

References Cited

Ahmadiana M, Li C, Lui Y, Fonsah EG, Bliss CM, Brodbeck BV, Andersen PC. 2016. Profitability of organic vegetable production via sod-based rotation and conventional versus strip tillage in the southern Coastal Plain. Sustainable Agricultural Research 5: 46–54.

Andersen PC, Brodbeck BV, Bliss CM, McSorley RM. 2016. Influence of crop rotation, and years in bahiagrass on plant-parasitic nematode density in an organic vegetable production system. Nematropica 46: 60–70.

Bliss C, Andersen PC, Brodbeck BV, Wright D, Olson S, Marois J. 2016. The influence of bahiagrass, tillage and cover crops on organic acid production and soil quality in the Southern Coastal Plain. Sustainable Agricultural Research 5: 65–82.

Brodbeck BV, Strong DR. 1987. Amino acid nutrition of herbivorous insects and stress to host plants, pp. 347–364 *In* Barbosa P, Schultz JC [eds.], Insect Outbreaks. Academic Press, New York, USA.

Caprio E, Nervo B, Isaia M, Allegro G, Rolando A. 2015. Organic versus conventional systems in viticulture: comparative effects of spiders and carabids in vineyard and adjacent forests. Agricultural Systems 136: 61–69.

Carter MR, Noronha C, Peters RD, Kimpinski J. 2009. Influence of conservation tillage and crop rotation on the resilience of an intensive long-term potato cropping system: restoration of soil biological properties after the potato phase. Agriculture, Ecosystems and Environment 133: 32–39.

Chiverton PA. 1987. Predation of *Rhopalosiphum padi* (Hom: Aphididae) by polyphagous predatory arthropods during the aphids' pre-peak period in spring barley. Annals of Applied Biology 111: 257–269.

Clark TE, Samways MJ. 1997. Sampling arthropod diversity for urban ecological landscaping in a species-rich southern hemisphere botanic garden. Journal of Insect Conservation 1: 221–234.

Collins KL, Boatman ND, Wilcox A, Holland JM, Chaney K. 2002. Influence of beetle banks on cereal aphid predation in winter wheat. Agriculture, Ecosystems and Environment 93: 337–350.

Crowder DW, Northfield TD, Strand MR, Snyder WE. 2010. Organic agriculture promotes evenness and natural pest control. Nature 466: 109–112.

Do Y, Kim JY, Kim HW, Joo G. 2017. Distribution of carabid beetles within wildlife corridors connecting fragmented forests. Landscape and Ecological Engineering 13: 279–286.

Dogliotti S, Rossing WAH, Van Ittersum MK. 2004. Systematic design and evaluation of crop rotations enhancing soil conservation, soil fertility and farm income: a case study for vegetable farms in South Uruguay. Agricultural Systems 80: 277–302.

Elkins CB, Haaland RL, Hoveland CS. 1977. Grass roots as a tool for penetrating soil hardpans and increasing crop yields, pp. 21–26 *In* Proceedings of the 34th Southern Pasture and Forage Crop Improvement Conference, Auburn University, Auburn, Alabama, USA.

Ellis Jr JD, Neumann P, Hepburn R, Elzen PJ. 2002. Longevity and reproductive success of *Aethina tumida* (Coleoptera: Nitidulidae) fed different natural diets. Journal of Economic Entomology 95: 902–907.

Endale DM, Bosch DD, Potter TL, Strickland TC. 2014. Sediment loss and runoff from cropland in a Southeast Coastal Plain landscape. Transactions of the Society of Agricultural and Biological Engineers 57: 1611–1626.

Greenstone MH. 2016. Sampling epigeal arthropods: a permanent, sheltered, closeable pitfall trapping station. Journal of Entomological Science 51: 87–93.

Hatten TD, Bosque-Perez NA, Johnson-Maynard J, Eigenbrode SD. 2007. Tillage differentially affects the capture rate of pitfall traps for three species of carabid beetles. Entomologia Experimentalis et Applicata 124: 177–187.

Holland JM. 1998. The effectiveness of exclusion barriers for polyphagous predatory arthropods in wheat. Bulletin of Entomological Research 88: 305–310.

Holland JM, Reynolds CJM. 2003. The impact of soil cultivation on arthropod (Coleoptera and Araneae) emergence on arable land. Pedobiologia 47: 181–191.

Hummel RL, Walgenbach JF, Hoyt GD, Kennedy GG. 2002. Effects of vegetable production system on epigeal arthropod populations. Agriculture, Ecosystems and Environment 93: 177–188.

Kashirad AJ, Fiskell GA, Carlisle VW, Hutton CE. 1967. Tillage pan characterization of selected coastal plain soils. Journal of the Soil Science Society of America 31: 534–541.

Katsvairo TW, Rich JR, Dunn RA. 2006. Perennial grass rotation: an effective and challenging tactic for nematode management with many other positive effects. Pest Management Science 62: 793–796.

Katsvairo TW, Wright DL, Marois JJ, Hartzog DL, Balkcom KB, Waitrak PJ, Rich JR. 2007. Cotton roots, earthworms and infiltration characteristics in sod-peanut-cotton cropping systems. Journal of Agronomy 99: 390–398.

Khalilian A, Jones MA, Bauer PJ, Marshall MW. 2017. Comparison of five tillage systems in Coastal Plains soils for cotton production. Open Journal of Soil Science 7: 245–258.

Kotze DJ, Brandmayr P, Casale A, Duffy-Richard E, Dekoninck W, Koivula MJ, Lövei GL, Mossakowski D, Noordijk J, Paarmann W, Pizzolotto R, Saska P, Schwerk A, Serranno J, Szyszko J, Taboada A, Turin H, Venn S, Vermeulen R, Zetto T. 2011. Forty years of carabid beetle research in Europe – from taxonomy, biology, ecology and population to bioindication, habitat assessment and conservation. Zookeys 100: 55–148.

Kromp B. 1999. Carabid beetles in sustainable agriculture: a review of pest control efficacy, cultivation impacts and enhancements. Agriculture, Ecosystems and Environment 74: 187–228.

Kuepper G, Gegner L. 2004. Organic crop production overview. ATTRA Publication #IP170, National Center for Appropriate Technology, Fayetteville, Arkansas, USA.

Labruyere S, Ricci B, Lubac A, Petit S. 2016. Crop type, crop management and grass margins affect the abundance and the nutritional state of seed-eating carabid species in arable landscapes. Agriculture, Ecosystems and Environment 231: 183–192.

Landis DA, Wratten SD, Gurr GM. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology 45: 175–201.

Leslie TW, Hoheisel GA, Biddinger DJ, Rohr JR, Fleisher SJ. 2007. Trans genes sustain epigeal insect biodiversity in diversified vegetable farm systems. Environmental Entomology 36: 234–244.

Lövei GL, Sunderland KD. 1996. Ecology and behavior of ground beetles (Coleoptera: Carabidae). Annual Review of Entomology 41: 231–256.

Lundgren JG, Shaw JT, Zaborski ER, Eastman CE. 2006. The influence of organic transition systems on beneficial ground-dwelling arthropods and predation of insects and weed seeds. Renewable Agriculture and Food Systems 21: 227–237.

Marois JJ, Wright DL, Baldwin JA, Hartzog DL. 2002. A multistate project to sustain peanut and cotton yields by incorporating cattle in a sod-based rotation, pp. 101–110 *In* van Santen E [ed.], Proceedings of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture, 24–26 Jun 2002, Auburn, Alabama, USA.

MacLeod A, Wratten SD, Sotherton NW, Thomas MB. 2004. 'Beetle banks' as refuges for beneficial arthropods in farmland: long-term changes in predator communities and habitat. Agriculture and Forest Entomology 6: 147–154.

Obrist MK, Duelli P. 1996. Trapping efficiency of funnel- and cup-traps for epigeal arthropods. Mitteilungen der Schweizerische Entomologischen Gesellschaft 69: 361–369.

Peigne J, Ball BC, Roger-Estrade J, David C. 2007. Is conservation tillage suitable for organic farming? A review. Soil Use and Management 23: 129–144.

Pereira JL, Picanco MC, Pereira EJG, Silva AA, Jeakelaitis A, Pereira RR, Xavier VM. 2010. Influence of crop management practices on bean foliage arthropods. Bulletin of Entomological Research 100: 679–688.

Poveda K, Steffan-DeWenter I, Scheu S, Tscharntke T. 2006. Belowground effects of organic and conventional farming on aboveground plant-herbivore and plant-pathogen interactions. Agriculture, Ecosystems and Environment 113: 162–167.

Purtauf T, Roschewitz I, Dauber J, Theis C, Tscharntke T, Wolters V. 2005. Landscape context of organic and conventional farms: influences of carabid beetle diversity. Agriculture, Ecosystems and Environment 108: 165–174.

Rivers A, Mullen C, Wallace J, Barbercheck M. 2017. Cover crop-based reduced tillage system influences Carabidae (Coleoptera) activity, diversity and tro-

phic group during transition to organic production. Renewable Agriculture and Food Systems 32: 538–551.
Rondon SL, Pantoja A, Hagerty A, Horneck DA. 2013. Ground beetle (Coleoptera: Carabidae) populations in commercial organic and conventional potato production. Florida Entomologist 96: 1492–1499.
Sandhu HS, Wratten SD, Cullen R. 2010. The role of supporting ecosystem services in conventional and organic arable farmland. Ecological Complexity 7: 302–310.
SAS Institute Inc. 2009. SAS/STAT User's Guide, Vers. 9.2. Cary, North Carolina, USA.
Smukler SM, Sanchez-Moreno S, Fonte SJ, Ferris H, Klonsky K, O'Green AT, Scow KM, Steenwerth KL, Jackson LE. 2010. Biodiversity and multiple ecosystem functions in an organic farmscape. Agriculture, Ecosystems and Environment 139: 80–97.
Stuhl CJ. 2017. Survival and reproduction of small hive beetles (Coleoptera: Nitidulidae) on commercial pollen substitutes. Florida Entomologist 100: 693–697.
Thomas SR, Noordhuis R, Holland JM, Goulson D. 2002. Botanical diversity of beetle banks: effects of age and comparison with conventional arable field margins in the Southern UK. Agriculture, Ecosystems and Environment 93: 403–412.
West JT, Beinroth FH, Sumner ME, Kang BT. 1997. Utisols: characteristics and impacts on society. Advances in Agronomy 63: 179–236.
Westerman PR, Borza JK, Andjelkovic J, Liebman M, Danielson B. 2008. Density-dependent predation of wed-seeds in maize fields. Journal of Applied Ecology 45: 1612–1620.
Wiatrak PJ, Wright DL, Marois JJ. 2004a. Influence of residual nitrogen and tillage on white lupin. Agronomy Journal 96: 1765–1770.
Wiatrak PJ, Wright DL, Marois JJ. 2004b. Evaluation of tillage and poultry litter applications on peanut. Agronomy Journal 96: 1125–1130.
Wiatrak PJ, Wright DL, Marois JJ. 2006. Influence of tillage and residual nitrogen on wheat. Soil and Tillage Research 91: 150–156.