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Source: Florida Entomologist, 94(2) : 226-232

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.094.0215

# EFFECT OF ORGANIC MULCHES ON SOIL SURFACE INSECTS AND OTHER ARTHROPODS

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ABSTRACT

Four different types of organic mulches were evaluated for their effects on soil surface insects and related arthropods. Field experiments were conducted in fall 2007 and 2008 near Citra, Florida. In both the years, five treatments were compared: cowpea (*Vigna unguiculata* (L.) Walp.) mulch, sunn hemp (*Crotalaria juncea* L.) mulch, sorghum-sudangrass (*Sorghum bicolor* Moench × *S. sudanense* ((Piper)] Stapf) mulch, pine bark nuggets, and unmulched control. Data were collected on insects and other arthropods using pitfall traps. Results indicate that organic mulches can affect a wide range of different insects. Diptera, dominated by *Asyndetus* spp. (Dolichopodidae), were most dense in pine bark plots in both years. Populations of small plant-feeding insects such as Aphididae, Thripidae, and Aleyrodidae were most dense in cowpea and unmulched control plots in one season. It is possible that these insects were affected by weed growth in cowpea and control plots. Ants, which tend or feed on small plant feeders, were fairly abundant in these plots as well, as were predatory beetles. Some groups, such as Collembola (mainly Isotomidae), spiders, and Orthoptera (Acrididae and Gryllidae) were unaffected by mulches.

Key Words: cover crop residue, organic mulch, insect community, pine bark

RESUMEN

Se evaluaron cuatro diferentes tipos de coberturas orgánicas por sus efectos sobre los insectos y artrópodos relacionados de la superficie del suelo. Se realizaron los experimentos de campo en el otoño del 2007 y 2008 cerca de Citra, Florida. En ambos años, se compararon cinco tratamientos: el mantillo de caupí (*Vigna unguiculata* (L.) Walp.), el mantillo de cáñamo sunn (*Crotalaria juncea* L.), el mantillo de sorgo-pasto de Sudán (*Sorghum bicolor* Moench * *S. sudanense* (Piper) Stapf), pedazos de la corteza de pino, y sin cobertura (control). Se utilizaron trampas de caída para obtener los datos de los insectos y de los otros artrópodos. Los resultados indican que el mantillo orgánico puede afectar a una amplia gama de diferentes insectos. Los Diptera, dominado por las especies de *Asyndetus* (Dolichopodidae), fueron más densas en parcelas de corteza de pino en ambos años. Las poblaciones de insectos que se alimentan de plantas pequeñas, tales como Aphididae, Thripidae y Aleyrodidae eran más densas en caupí y parcelas sin cobertura (control) en una temporada. Es posible que estos insectos fueron afectados por el crecimiento de malezas en las parcelas de caupí y del control. Las hormigas, que atienden o se alimentan de insectos que se alimentan de plantas pequeñas, fueron bastante abundantes en estas parcelas, al igual que los escarabajos depredadores. Algunos grupos, como los colémbolos (principalmente Isotomidae), arañas, y ortópteros (Acrididae y Gryllidae) no fueron afectados por las coberturas.

Use of cover crop residues as organic mulches has a number of advantages to farming systems such as reducing soil erosion, conserving soil moisture, moderating soil temperature, improving infiltration of water, and providing a slow-release source of nutrients (Gruda 2008; Hatwig & Ammon 2002; Hatwig & Hoffman 1975; Powers & McSorley 2000; Snapp et al. 2005; Westerman & Bicudo 2005). Plant mulches can be an effective way to provide shelter for predatory insects (Johnson et al. 2004) and to control weeds (Reeleder et al. 2004; Teasdale et al. 2004). Mulches can help to maintain soil moisture required for plant vigor and to promote plant tolerance to the attack of insect pests (Johnson et al. 2004).

Cover crops and intercrops have been used as living mulches for managing some insect pests. Alfalfa (*Medicago sativa* L.) and kura clover (*Trifolium ambiguum* M. Bieb.) mulches increased predator populations to manage European corn borer (*Ostrinia nubilalis* Hübner) (Prasifka et al. 2006). Eggs and larval densities of pest caterpillars were higher in broccoli (*Brassica oleracea* L. var. *botrytis*) monoculture when compared to broccoli with undersown mulches like strawberry clover (*Tribolium fragiferum* L.), white clover (*Tribolium repens* L.), and yellow sweet clover (*Melilotus officinalis* L.) (Hooks & Johnson 2004). Alfalfa living mulch increased predators to manage outbreaks of the invasive soybean aphid, *Aphis glycines* Matsumura (Schmidt et al. 2007).

While these examples suggest that living mulches may offer resources to support predators, non-living mulches derived from killed cover crops, hay from cover crops, or composted waste products may offer benefits as well. In sweetpotato (*Ipomoea batatas* (L.) Lam.), higher numbers of fire ants, rove beetles, and carabid beetles were captured using pitfall traps in plots covered with killed-cover crop (Jackson & Harrison 2008). Also, the injury level from soil insect pests to roots of sweetpotato was lower in killed-cover crop plots than in conventional plots. In an apple (*Malus domestica* Borkh.) orchard, the dominance of several carabid species depended on different factors including sampling dates and different types of ground cover including plastic mulch and straw mulch (Miñarro & Dapena 2003). Predation of beet armyworm, *Spodoptera exigua* (Hübner), pupae was 33% greater in cover crop mulch as compared with conventional production plots (Pullaro et al. 2006). Mulch from sunn hemp (*Crotalaria juncea* L.) hay was effective in reducing incidence of lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller) on bean (*Phaseolus vulgaris* L.) (Gill et al. 2010).

Changes in cropping systems affect insect pests and their natural enemies (Hummel et al. 2002). Organic mulches might provide hiding places to harbor populations of natural enemies. Different types of cover crops harbor distinctive complexes of beneficial insects, pest arthropods, and their diverse trophic relationships (Bugg & Waddington 1994). Many previous studies that used mulches for the management of insect pests focused especially on flying insects moving into mulched areas (Brown & Tworkoski 2004; Gill et al. 2010; Hooks & Johnson 2004; Prasifka et al. 2006; Pullaro et al. 2006; Reeleder et al. 2004; Schmidt et al. 2007; Tremelling et al. 2002). The effects of mulches on insects and other soil arthropods living on the soil surface is a relatively less explored area.

More information is needed on arthropods that are active on the soil surface where the mulches occur, and how different materials on the soil surface affect these arthropods. To answer these questions, the present study was designed with main objective to determine the impact of mulches on the community of arthropods that live and move on the soil surface. The purpose was to obtain an overview of various arthropod groups that were active on the soil surface, rather than focusing on selected key species.

## Materials and Methods

Field experiments were conducted in fall 2007 and 2008 at the University of Florida Plant Science Research and Education Unit (29°24'N, 82°9'W), Citra, Florida. The soil at the experimental site was Arredondo sand (95% sand, 2% silt, 3% clay) with 1.5% organic matter (Thomas et al. 1979).

### Fall 2007

The experimental field was sprayed with glyphosate (Roundup®, Monsanto, St. Louis, Missouri) to kill weeds on Sep 26 followed by rototilling on Oct 3. Average soil moisture measured gravimetrically before planting was 6.1%. Five treatments compared were: cowpea (*Vigna unguiculata* (L.) Walp.) mulch; sunn hemp mulch; sorghum-sudangrass (*Sorghum bicolor* Moench × *S. sudanense* (Piper) Stapf) mulch; pine bark nuggets as mulch (HTC Hood Timber Co., Adel, GA); and unmulched control. Treatments were arranged in a randomized complete block design with five replications (total of 25 plots). Individual plots for each treatment were 3.0 m long and 2.4 m wide and the distance between plots was 3.0 m. All plots were planted with 'Roma II' bush beans (*Phaseolus vulgaris* L.) on Oct 4. Seeds were spaced 10 cm apart at a rate of 30 seeds per row, in two rows per plot.

The mulches used were readily available or easily supplied by cover crop residues. Cover crop mulches were obtained from crops of 'Iron and Clay' cowpea, 'Tropic Sun' sunn hemp, and 'Growers Choice' sorghum-sudangrass planted in early Jul. Mulches were obtained from these cover crops (prior to flowering) planted near the experimental site. To obtain mulches, these cover crops were harvested on Oct 11 by clipping plants at the base, removing above-ground biomass, and applying it to the plots The resulting mulches (3-5 cm deep) were a composite of leaves and stems and were applied by hand over the entire plot, next to the rows of bean plants. Therefore, except for the plant rows, the entire plot was covered with mulch. Mulches were applied only once at the start of experiment on Oct 11, using the following amounts of material: cowpea (18.1 kg fresh wt/ plot), sunn hemp (15.9 kg fresh wt/ plot), and sorghum-sudangrass (17.7 kg fresh wt/plot). The pine bark nuggets (29.8 kg fresh wt/plot) were not obtained from cover crops, but were purchased locally. Plots were irrigated as needed using drip irrigation, and no insecticides were applied during the course of the experiment.

### Fall 2008

The experiment was repeated at the same site in the fall 2008, with the same treatments. Experimental procedures remained the same with a few minor changes. The experimental field was sprayed with glyphosate to kill weeds in the first week of Sep followed by rototilling on Sep 16. Average soil moisture measured gravimetrically at planting was 6.9%. Beans were planted on Oct 7. Cowpea (12.7 kg fresh wt/plot), sunn hemp (15.9 kg fresh wt/plot), sorghum-sudangrass (13.6 kg fresh wt/plot), and pine bark nuggets (29.8 kg fresh wt/plot) were applied on Oct 9. Early frost in each season caused severe damage to the bean plants, so that crop harvests were not possible.

Data collection

Insects were collected on several sampling dates in both seasons (Oct 24, Nov 6, Nov 20, Dec 3, and Dec 17 in 2007; Oct 13, Oct 28, Nov 9, and Nov 24 in 2008). Pitfall traps were used for capturing insects that run or move on the soil surface (Borror et al. 1989). A plastic sandwich container (14 cm × 14 cm × 4 cm) was used as a pitfall trap. One pitfall trap was placed in the middle of each plot, and buried so that the upper edge was flush with the soil surface. The traps were filled three quarters with water, along with 3 to 4 drops of dish detergent (Ultra Joy®, Procter and Gamble, Cincinnati, Ohio) to break surface tension, ensuring that the insects would remain in the trap. Pitfall traps were set out in the morning (9:00 am) and collected at approximately the same time (9:00 am) the next day (which was recorded as the sampling date). The traps were brought to the laboratory, kept in a cold room at 10°C, and contents transferred and stored in 70% ethanol in vials. Insects and related arthropods were identified to order and family levels using a dissecting microscope.

Data analysis

All statistical analyses were performed using the Statistical Analysis System (SAS) package (version 9.1; SAS Institute, Cary, North Carolina). Data for each dependent variable (insect groups) were analyzed across all sampling dates in each year using repeated measures (PROC MIXED procedure of SAS) to examine the effects of treatment, sampling date, and interactions between treatments and sampling dates. Since no interactions were found, data were pooled across sampling dates for calculations of means and standard errors of the means. When treatment effects were significant ($P \leq 0.05$), least square means (LS) values were computed to compare means of mulch treatments.

## RESULTS

Fall 2007

Diptera were affected ($P \leq 0.05$) by mulches, and were more common in pine bark mulch than in sunn hemp and sorghum-sudangrass (Table 1). Diptera consisted mainly of Dolichopodidae (43.9%, *Asyndetus* spp.) followed by Mycetophilidae (fungus gnats) and other micro-dipterans (37.1%) and other Diptera (19.0%). Cicadellidae and small plant-feeding insects were not significantly ($P \leq 0.05$) affected by treatment, but Cicadellidae showed some an interesting trend ($P \leq$

TABLE 1. EFFECT OF MULCH TREATMENTS ON ARTHROPOD TAXA (NUMBERS/PITFALL TRAP) THROUGHOUT THE SEASON IN CITRA, FLORIDA, 2007.

| Treat[1] | Hymenoptera[2] | Collembola[2] | Homoptera[2] | Diptera[2] | Orthoptera[2] | Araneae | Coleoptera[2] | Others[2] |
|---|---|---|---|---|---|---|---|---|
| CP | 6.48 ± 1.51 a | 58.52 ± 8.76 a | 1.48 ± 0.29 a | 5.56 ± 0.71 ab | 1.28 ± 0.37 a | 0.52 ± 0.13 a | 2.16 ± 0.50 a | 1.64 ± 0.34 a |
| SH | 5.08 ± 1.42 a | 138.20 ± 42.39 a | 1.04 ± 0.30 a | 4.12 ± 0.67 b | 0.60 ± 0.16 a | 0.76 ± 0.18 a | 1.48 ± 0.32 a | 0.72 ± 0.20 a |
| SO | 6.96 ± 3.22 a | 70.00 ± 11.53 a | 1.32 ± 0.30 a | 4.32 ± 0.68 b | 0.84 ± 0.21 a | 0.68 ± 0.15 a | 1.80 ± 0.33 a | 0.92 ± 0.36 a |
| PB | 3.00 ± 0.64 a | 84.36 ± 30.78 a | 0.88 ± 0.22 a | 7.32 ± 0.99 a | 1.24 ± 0.25 a | 1.08 ± 0.57 a | 0.96 ± 0.20 a | 1.04 ± 0.26 a |
| C | 2.52 ± 0.51 a | 86.80 ± 27.82 a | 2.80 ± 1.03 a | 5.28 ± 0.86 ab | 1.00 ±0.45 a | 0.48 ± 0.13 a | 1.52 ± 0.37 a | 1.44 ± 0.35 a |
| P > F | 0.2638 | 0.4128 | 0.0899 | 0.0111 | 0.4928 | 0.5136 | 0.1918 | 0.2272 |
| F value | 1.42 | 1.04 | 2.34 | 4.32 | 0.88 | 0.84 | 1.69 | 1.55 |

[1]Treatments CP = cowpea, SH = sunn hemp, SO = sorghum-sudangrass, PB = pine bark, C = unmulched control

[2]Hymenoptera = Formicidae; Collembola = Isotomidae and Sminthuridae; Homoptera = Cicadellidae; Diptera = Dolichopodidae, Mycetophilidae and micro-dipterans; Orthoptera = Acrididae and Gryllidae; Coleoptera = Staphylinidae, Carabidae, Elateridae, and Chrysomelidae; others = Aphididae, Aleyrodidae, and Thripidae

Data are means ± standard error of 25 replications (data pooled across 5 sampling dates). Means in columns for each sampling date followed by the same letters do not differ significantly based on least square means (P ≤ 0.05).

0.10) toward greater abundance in unmulched control plots. Small plant-feeding insects consisted of aphids (72.7%, Aphididae), whiteflies (24.3%, Aleyrodidae), and thrips (3.0%, Thripidae). The numbers of Formicidae (mixture of *Pheidole* spp., and *Dorymyrmex* spp.), Collembola (Isotomidae with a few Sminthuridae), Orthoptera (mixture of *Melanoplus* spp., *Dichromorpha* spp., and *Gryllus* spp.), Araneae, and Coleoptera (Staphylinidae, Carabidae, Elateridae, and Chrysomelidae) did not differ among treatments (Table 1). In addition, the few micro-Hymenoptera (mainly small parasitoid wasps) collected were also not affected by treatments (data not shown). Beetles collected were from the families Staphylinidae (23.4%), Carabidae (12.2%, *Anisodactylus* spp.), Elateridae (14.2%, *Conoderus* spp.), and Chrysomelidae (48.4%, *Altica* spp.), but none of these individual families were significantly ($P \le 0.05$) affected by treatments. A few specimens of other plant-feeding insects were occasionally recovered at low levels in pitfall traps, including cutworms (Noctuidae), plant hoppers (Fulgoridae), spittlebugs (Cercopidae), and stink bugs (Pentatomidae), but none were affected by treatments ($P \ge 0.10$).

### Fall 2008

In this season, Diptera were more common in pink bark mulch than in sunn hemp and unmulched control plots (Table 2). Diptera consisted mainly of Dolichopodidae (81.1%) followed by fungus gnats (Mycetophilidae) and other microdipterans (3.7%) and other Diptera (15.2%). Formicidae were affected by mulches, and were greatest in cowpea plots. Total numbers of beetles were greater in unmulched control and cowpea than in sorghum-sudangrass. Beetles collected were from the families Staphylinidae (71.7%), Carabidae (21.6%), Elateridae (3.2%), and Chrysomelidae (3.4%), but none of these individual families were significantly ($P \le 0.05$) affected by treatments. Small plant-feeding insects were most abundant in cowpea and unmulched control plots. Small plant-feeding insects consisted of aphids (73.0%, Aphididae), whiteflies (26.0%, Aleyrodidae), and thrips (0.9%, Thripidae). The numbers of Cicadellidae, Araneae, Collembola (mostly Isotomidae), and Orthoptera (Acrididae and Gryllidae) collected did not differ among treatments (Table 2).

## Discussion

The arthropods recovered during this study encompassed a variety of trophic groups and feeding habits (Table 3). Effects of treatments on different insect groups varied, but some interesting patterns were evident. Several insect groups, including ants, beetles, and small plant feeding in-

TABLE 2. EFFECT OF MULCH TREATMENTS ON ARTHROPOD TAXA (NUMBERS/PITFALL TRAP) THROUGHOUT THE SEASON IN CITRA, FLORIDA, 2008.

| Treat[1] | Hymenoptera[2] | Collembola[2] | Homoptera[2] | Diptera[2] | Orthoptera[2] | Araneae | Coleoptera[2] | Others[2] |
|---|---|---|---|---|---|---|---|---|
| CP | 12.00 ± 1.80 a | 22.20 ± 2.87 a | 3.90 ± 0.99 a | 9.85 ± 1.94 ab | 2.95 ± 0.85 a | 0.45 ± 0.15 a | 2.25 ± 0.70 ab | 6.00 ± 1.27 a |
| SH | 4.49 ± 0.96 b | 27.00 ± 6.29 a | 2.05 ± 0.52 a | 6.60 ± 1.23 b | 1.70 ± 0.41 a | 1.00 ± 0.74 a | 1.20 ± 0.28 bc | 1.70 ± 0.52 bc |
| SO | 3.75 ± 0.95 b | 28.00 ± 4.66 a | 3.10 ± 0.63 a | 10.10 ± 1.92 ab | 1.65 ± 0.47 a | 1.15 ± 0.46 a | 1.15 ± 0.29 c | 3.00 ± 0.62 bc |
| PB | 3.80 ± 0.72 b | 28.60 ± 3.68 a | 1.75 ± 0.34 a | 14.30 ± 2.08 a | 1.50 ± 0.48 a | 0.40 ± 0.15 a | 1.30 ± 0.42 bc | 1.10 ± 0.23 c |
| C | 5.10 ± 0.84 b | 38.70 ± 8.59 a | 3.90 ± 1.00 a | 7.65 ± 1.35 b | 2.10 ± 0.56 a | 0.25 ± 0.10 a | 2.50 ± 0.55 a | 4.15 ± 0.88 ab |
| *P* > F | <0.0001 | 0.4777 | 0.2364 | 0.0050 | 0.1500 | 0.5105 | 0.0439 | <0.0001 |
| F value | 14.76 | 0.91 | 1.51 | 5.17 | 1.90 | 0.85 | 2.99 | 12.88 |

[1]Treatments CP = cowpea, SH = sunn hemp, SO = sorghum-sudangrass, PB = pine bark, C = unmulched control

[2]Hymenoptera = Formicidae; Collembola = Isotomidae; Homoptera = Cicadellidae; Diptera = Dolichopodidae, Mycetophilidae and micro-dipterans; Orthoptera = Acrididae and Gryllidae; Coleoptera = Staphylinidae, Carabidae, Elateridae, and Chrysomelidae; others = Aphididae, Aleyrodidae, and Thripidae.

Data are means ± standard error of 20 replications (data pooled across 4 sampling dates). Means in columns for each sampling date followed by the same letters do not differ significantly based on least square means ($P \le 0.05$).

TABLE 3. ARTHROPODS AND THEIR FEEDING HABITS IN THE NATURAL ENVIRONMENT.

| Arthropods | Feeding habits | References |
|---|---|---|
| Hymenoptera (Formicidae: *Pheidole, Dorymyrmex*) | Mainly predators of small invertebrates<br>Some ants feed on plant sap, nectar, honeydew or fungi | Wilson 2005<br>Triplehorn & Johnson 2005 |
| Collembola (Isotomidae and Sminthuridae) | Usually fungi associated with decaying vegetation | Coleman et al. 2004 |
| Homoptera (Cicadellidae) | Mainly herbivores feeds on plant sap | Redak et al. 2003 |
| Diptera (Dolichopodidae: *Asyndetus*, and Mycetophilidae) | Dolichopodidae mainly predators of small invertebrates<br>Mycetophilidae feed on fungus | Ulrich & Schmelz 2001<br>Triplehorn & Johnson 2005 |
| Orthoptera (Gryllidae: *Gryllus*, and Acrididae: *Melanoplus*, *Dichromorpha*) | Generalist herbivores, feed on most kinds of vegetation including weeds | Capinera 1993 |
| Araneae | Generalist predators of small-sized arthropods | Riechert & Lockley 1984 |
| Coleoptera: (Staphylinidae), | Most Staphylinidae are facultative predators | Frank & Thomas 2010 |
| Carabidae: (*Anisodactylus* spp.), | *Anisodactylus* spp. are typically predators but granivory has been recently reported | Sasakawa 2009 |
| Elateridae: (*Conoderus* spp.), | *Conoderus* spp. eat seeds, and feed on stem and roots of seedlings and lead to weak plant stand | Mossler 1993, |
| and Chrysomelidae: (*Altica* spp.) | *Altica* spp. generally feed on different kinds of plants | Jenkins et al. 2009 |
| Others (Aphididae, Aleyrodidae, and Thripidae) | Plant feeders | Triplehorn & Johnson 2005 |

sects (aphid, whiteflies, and thrips), were highest in unmulched control or cowpea plots in one season. It is possible that weeds (including nutsedges, grasses, and broadleaf) in unmulched control and cowpea plots may have led to the higher numbers of small plant-feeding insects in these plots. Cowpea mulch degraded quickly and allowed the emergence of weeds after 3-4 weeks. At this time, broadleaf weeds covered about 10% of the surface area in unmulched control and cowpea plots, but <5% in other plots. Broadleaf weeds consisted of Florida pusley (*Richardia scabra* L.), eveningprimrose (*Oenothera laciniata* Hill.), and cudweed (*Gnaphalium* spp.).

Beetles are the largest and most diverse group of insects, and varied in their response to treatment over the two seasons, reaching highest numbers in cowpea plots in 2008. The majority of these were Staphylinidae and Carabidae, which are predators, and the increased abundance of potential prey insects (Aphididae, Cicadellidae etc.) in unmulched control plots may have stimulated these predatory beetles as well (Table 3). Ants have been observed to feed on or tend sucking insects such as aphids and whiteflies (Borror et al. 1989), so their increased numbers may be related to the other insects in unmulched control and cowpea plots. This effect was observed by Pullaro et al. (2006) who recorded a greater number of fire ants in plots with killed-cover crop mulch compared with conventional plots. Flies were most common in pine bark plots in both years, possibly because pine bark was the only mulch that did not degrade as fast as others (C:N ratio = 208:1), and may have served as cover for these insects and their larvae. This mulch may have provided favorable habitat for long-legged flies (Dolichopodidae) that typically inhabit organic debris and feed on small invertebrates on the soil surface (Borror et al. 1989; Triplehorn & Johnson 2005; Ulrich & Schmelz 2001). Collembola were unaffected by treatments, with similar levels in mulched and unmulched plots. This was unexpected since the degradation of mulch could provide a continuous supply of organic matter. Generally, Collembola are cryptozoic and feed on fungi associated decaying organic matter (Coleman et al. 1996; Powers & McSorley 2000).

We were surprised to find a number of aphids, whiteflies, and thrips in pitfall traps. The pitfall trap is the one of the most commonly used methods to sample insects and other arthropods on the soil surface (Southwood & Henderson 2000). On the other hand, small plant feeders such as aphids, whiteflies, and thrips are typically sampled by other methods such as sticky cards rather than pitfall traps (Southwood & Henderson 2000). However, small numbers of them will fall from vegetation into pitfall traps as well (Tremelling et al. 2002). Future studies should anticipate presence of some small plant feeders in pitfall traps, which could probably be better explained by concurrent sampling of above-ground vegetation by other methods.

## Conclusions

The present study suggests that insects varied in their responses to different mulches. During both years, flies (mainly Dolichopodidae) were found in highest numbers in pine bark plots throughout the season. Several other groups were affected indirectly due to the effects of mulches on weed growth. Weed growth in unmulched control and cowpea plots may have led to increased populations of small plant feeders such as aphids, thrips, and whiteflies. Ants that tend or feed on small plant feeders were more abundant in these plots as well, as were predatory beetles in 2008. Some groups, such as Collembola, spiders, and parasitoid wasps, were unaffected by mulches, while others such as leafhoppers showed only minimal trends.

## Acknowledgments

This paper is submitted in partial fulfillment of the requirements for the PhD degree of the senior author. The authors also thank Heidi HansPetersen, Namgay Om, and Romy Krueger for their assistance in the field, and Buck Nelson and the staff of PSREU for management of field plots. Lyle Buss of the Entomology and Nematology Department at the University of Florida was very helpful with identification of some of the insect genera. The authors also thank Danielle Treadwell, Gaurav Goyal, and Susan Webb of the University of Florida for reviewing and improving an earlier version of the manuscript. Mention of any trade names or products does not imply endorsement or recommendation by the University of Florida or USDA.

## References Cited

Borror, D. J., Triplehorn, C. A., and Johnson, N. F. 1989. An introduction to the study of insects, pp. 751-753, 6th ed. Saunders College Publishing, Chicago, Illinois.

Brown, M. W., and Tworkoski, T. 2004. Pest management benefits of compost mulch in apple orchards. Agric. Ecosyst. Environ. 103: 465-472.

Bugg, R. L., and Waddington, C. 1994. Using cover crops to manage arthropod pests of orchards: A review. Agric. Ecosyst. Environ. 50: 11-28.

Capinera, J. L. 1993. Host plant selection by *Schistocerca americana* (Orthoptera: Acrididae). Environ. Entomol. 22: 127-133.

Coleman, D. C., Crossley, D. A. Jr., and Hendrix, P. F. 2004. Secondary production: Activities of heterotrophic organisms- the soil fauna, pp. 51-106 *In* Fundamentals of Soil Ecology. Academic Press, San Diego, California.

Frank, J. H., and Thomas, M. C. 2010. Rove beetles of the world, Staphylinidae (Insecta: Coleoptera: Staphylinidae). EENY-114, Florida Cooperative extension Service, University of Florida, Gainesville, Florida. http://edis.ifas.ufl.edu/in271

GILL, H. K., MCSORLEY, R., GOYAL, G., AND WEBB, S. E. 2010. Mulch as a potential management strategy for lesser cornstalk borer, *Elasmopalpus lignosellus* (Insecta: Lepidoptera: Pyralidae), in bush bean (*Phaseolus vulgaris*). Florida Entomol. 93: 183-190.

GRUDA, N. 2008. The effect of wood fiber mulch on water retention, soil temperature and growth of vegetable plants. J. Sustain. Agric. 32: 629-643.

HATWIG, N. L., AND AMMON, H. 2002. Cover crops and living mulches. Weed Sci. 50: 688-699.

HARTWIG, N. L., AND HOFFMAN, L. D. 1975. Suppression of perennial legume and grass cover crops for notillage corn. Proc. Northeast. Weed Sci. Soc. 29: 82-88.

HOOKS, C. R., AND JOHNSON, M. W. 2004. Using undersown clovers as living mulches: effects on yields, lepidopterous pest infestation, and spider densities in a Hawaiian broccoli agroecosystem. Int. J. Pest Manag. 50: 115-120.

HUMMEL, R. L., WALGENBACH, J. F., HOYT, G. D., AND KENNEDY, G. G. 2002. Effects of production systems on vegetable arthropods and their natural enemies. Agric. Ecosys. Environ. 93: 165-176.

JACKSON, D. M., AND HARRISON, H. F., JR. 2008. Effects of killed-cover crop mulching system on sweetpotato production, soil pests, and insect predators in South Carolina. J. Econ. Entomol. 101: 1871-1880.

JENKINS, T. M., BRAMAN, K. S., CHEN, Z., EATON, T. D., PETTIS, G. V., AND BOYD, D. W. 2009. Insights into flea beetle (Coleoptera: Chrysomelidae: Galerucinae) host specificity from concordant mitochondrial and nuclear DNA phylogenies. Ann. Entomol. Soc. Am. 102: 386-395

JOHNSON, J. M., HOUGH-GOLDSTEIN, J. A., AND VANGESSEL, M. J. 2004. Effects of straw mulch on pest insects, predators, and weeds in watermelons and potatoes. Environ. Entomol. 33: 1632-1643.

MIÑARRO, M., AND DAPENA, E. 2003. Effects of groundcover management on ground beetles (Coleoptera: Carabidae) in an apple orchard. Appl. Soil Ecol. 23: 111-117.

MOSSLER, M. A. 1999. Crop profile for sweet corn in Florida. CIR-1233, Florida Cooperative Extension Service, University of Florida, Gainesville, Florida. http://edis.ifas.ufl.edu/pi034

POWERS, L. E., AND MCSORLEY, R. 2000. Ecological Principles of Agriculture. Delmar Thomson Learning, Albany, New York.

PRASIFKA, J. R., SCHMIDT, N. P., KOHLER, K.A., O'NEAL, M. E., HELLMICH, R. L., AND SINGER, J. W. 2006. Effects of living mulches on predator abundance and sentinel prey on a corn-soybean-forage rotation. Pest Manag. 35: 1423-1431.

PULLARO, T. C., MARINO, P. C., JACKSON, D. M., HARRISON, H. F., AND KEINATH, A. P. 2006. Effects of killed cover crop mulch on weeds, weed seed, and herbivores. Agric. Ecosyst. Environ. 115: 97-104.

REDAK, R. A., PURCELL, A. H., LOPES, J. R. S., BLUA, M. J., MIZELL III, R. F., AND ANDERSEN, P. C. 2003. The biology of xylem fluid-feeding insect vectors of *Xylella fastidiosa* and their relation to disease epidemiology. Ann. Rev. Entomol. 49: 243-270.

REELEDER, R. D., CAPELL, B. B., ROY, R. C., GROHS, R., AND ZILKEY, B. 2004. Suppressive effect of bark mulch on weeds and fungal diseases in ginseng (*Panax quinquefolius* L.). Allelopath. J. 13: 211-232.

RIECHERT, S. E., AND LOCKLEY, T. 1984. Spiders as biological control agents. Ann. Rev. Entomol. 29: 299-320.

SAS INSTITUTE. 2009. The SAS system 9.1 for Windows. SAS Institute, Cary, North Carolina.

SASAKAWA, K. 2009. Diet affects male gonad maturation, female fecundity, and larval development in the granivorous ground beetle, *Anisodactylus punctatipennis*. Ecological Entomol. 34:406-411.

SCHMIDT, N. P., O'NEAL, M. E., AND SINGER, J. W. 2007. Alfalfa living mulch advances biological control of soybean aphid. Environ. Entomol. 36: 416-424.

SNAPP, S. S., SWINTON, S. M., LABARTA, R., MUTCH, D., BLACK, J. R., LEEP, R., NYIRANEZA, J., AND O'NEIL, K. 2005. Evaluating cover crops for benefits, costs and performance within cropping system niches. Agron. J. 97: 322-32.

SOUTHWOOD, T. R. E., AND HENDERSON, P. A. 2000. Ecological methods, 3rd ed. Blackwell Science Ltd. Editorial, Oxford, London.

TEASDALE, J. R., ABDUL-BAKI, A. A., MILL, D. J., AND THORPE, K. W. 2004. Enhanced pest management with cover crop mulches. Acta. Hort. (ISHA). 638: 135-140.

THOMAS, B. P., LAW, L. JR., AND STANKEY, D. L. 1979. Soil survey of Marion County area, Florida. US Department of Agriculture Soil Conservation Service, Washington, DC.

TREMELLING, M. J., MCSORLEY, R., AND GALLAHER, R. N. 2002. Effect of winter cover crops on soil surface invertebrate community. Soil Crop Sci. Soc. Fla. Proc. 62: 77- 82.

TRIPLEHORN, C. A., AND JOHNSON, N. F. 2005. Borror and Delong's Introduction to the Study of Insects. $7^{th}$ ed. Thompson Brooks/Cole, Pacific Grove, California.

ULRICH, H., AND SCHMELZ, R. M. 2001. Enchytraeidae as prey of Dolichopodidae, recent and in Baltic amber (Oligochaeta; Diptera). Bonn. Zool. Beitr. 50:89-101.

WESTERMAN, P. W., AND BICUDO, J. R. 2005. Management considerations for organic waste use in agriculture. Bioresource Technol. 96: 215-221.

WILSON, E. O. 2005. Oribatid mite predation by small ants of the genus *Pheidole*. Insectes Sociaux 52:263-265.