

IMPACT OF MUSTARDS (BRASSICACEAE) GROWN AS COVER CROPS ON NON-
TARGET ARTHROPOD COMMUNITIES

BY

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THESIS

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Abstract

The effects of mustard varieties grown as cover crops on non-target arthropod communities and diversity were investigated in 2008. The abundance of carabid beetles, collembolans, and mites were monitored before, during, and after the seeding, growth, and incorporation of two mustard varieties ('Tilney' and 'Florida Broadleaf') individually or in combination, and in plots where no cover crops were grown. Species richness and diversity indices and principal response curves also were used to analyze and compare communities over time across the selected cover-crop treatments. Insects were collected from pitfall traps during four sampling periods in 2008: 06-09 April, 10-12 June, 24-27 June, and 17-19 July. Soil samples were collected in 2008 on 18 April, 2 June (1 week after planting of mustards), 29 June (shortly before incorporation of mustards), 18 July (2 weeks after incorporation of mustards), and 11 September and in 2009 on 25 May. A total of 528 carabid beetles representing 8 genera were recovered from pitfall traps in all plots combined in 2008. *Anisodactylus santaecrucis* Fabricius accounted for 54 percent of all carabids recovered, and *Poecilus chalcites* Say accounted for 32 percent. In general, total abundance of carabids and abundance of dominant species of carabids were not affected by the cover crops during growth or after incorporation. A total of 32,036 collembolans representing 10 genera from five families were recovered from soil cores from all plots and sample dates combined. One species, *Desoria trispinata* (MacGillivray) (Isotomidae), accounted for 82 percent of all collembolans collected. Overall abundance of collembolans and the abundance of each of three dominant species did not differ significantly among the cover-crop treatments on any of the sampling dates. Diversity indices indicated significant differences in collembolan communities among treatments on three dates, but the

impacts of the mustard cover crops on collembolan diversity were inconsistent. A total of 11,275 mites were identified from 31,798 mites recovered from soil cores in 2008 and 2009. On three dates in midsummer, 2008, overall mite density was significantly greater in plots where Tilney mustard was planted than in plots where no cover crop was planted. On 29 June, 2008, mite diversity was greater in plots where Tilney mustard was planted than plots where no cover crop was planted. On 18 July, 2008, densities of cunaxid mites were greater in plots where Tilney mustard was planted than plots where no cover crop was planted. Population peaks of predatory mites (Mesostigmata, Prostigmata: Cunaxidae) coincided with population peaks of collembolans. Overall, results indicate that the mustard cover crops had little significant effect on the abundance, diversity, species richness, or overall community dynamics of the taxa investigated. These data suggest that mustards grown as cover crops to provide suppression of weeds or plant pathogens or to increase soil tilth are likely have little effect on non-target soil arthropods.

To Mom, Dad, Arik and Rahul

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Introduction and Literature Review

Cover Cropping in Organic and Conventional Agriculture in the United States

Cover cropping is a practice used in agriculture to benefit the main crop and to minimize costs and environmental impacts of synthetic inputs. Cover crops are employed to slow soil erosion, conserve soil moisture, enhance organic matter, control soil-borne plant pathogens, inhibit weed growth, suppress arthropod pests, and improve yield and market value (Bowman et al. 1998). Addition of organic matter to the soil is positively correlated with soil quality, sustainability and productivity of crops and with increased carbon sequestration (Dinesh et al. 2009).

In 2008, of a total of 1.1 million hectares of land used in USDA-certified organic agriculture, approximately 36,000 acres of land were used for green manure cover crops (USDA, Economic Research Service 2010). In contrast, in 1997 approximately 2,800 hectares of land were used for green manure cover crop production (USDA, Economic Research Service 2010). The increase in land devoted to cover crops parallels a 15% annual increase of farmland dedicated to organic agriculture from 2002 to 2008 (USDA, Economic Research Service 2010) even though certified organic farmland remains a small fraction of total agricultural production.

Use of Mustards (Brassicales: Brassicaceae) as Cover Crops and Green Manures

Numerous species in the Brassicaceae, including rapeseed, *Brassica napus* (L.), turnip, *Brassica rapa* (L.), mustards, *Brassica* spp., *Sinapis* spp., and radish, *Raphanus sativus* (L.), are used as cover crops for many purposes, and investigation of mustards have focused on their pest control potential (Clark 2007). *Brassica* species and related winter cover crops also are efficient

at nitrogen capture after harvest, preventing winter leaching of nitrogen (Clark 2007). Their impacts on cropping systems differ by species. For example, winter rape, *Brassica napus* (L.), reduced incidence of soil-borne pathogens and suppressed weeds in organic potato production more effectively than white mustard, *Sinapis alba* (L.) (Eberlein 2000).

Plants in the Brassicaceae contain a diverse class of secondary compounds called glucosinolates. Over 120 glucosinolates have been characterized (Fahey et al. 2001) and are involved in plant defense against herbivory (Hopkins et al. 2009). When tissues are damaged, myrosinase hydrolyzes glucosinolates in the presence of water to produce a variety of byproducts – thiocyanates, isothiocyanates and nitriles. Isothiocyanates in particular are most associated with negative effects on generalist insect herbivores (Hopkins et al. 2009). They act as fumigants, and species in the genera *Brassica*, *Sinapis*, and *Armoracia* have been investigated as alternatives to synthetic soil fumigants such as methyl bromide (Monfort et al. 2007). In a study of biofumigant properties in soil against the whitefringed weevil, *Naupactus leucoloma* (Boheman) (Coleoptera: Curculionidae), methyl isothiocyanate was the most active isothiocyanate under all conditions. Results in general suggest that species rich in aliphatic isothiocyanates are more active as biofumigants than those rich in aromatic isothiocyanates (Matthiessen and Shackleton 2005).

Mustards used as green manures reduce the incidence of soil-borne fungal pathogens of plants (Larkin and Griffin 2007; Mari et al. 2008; Motisi et al. 2009). Allyl isothiocyanate from *Brassica nigra* (black mustard) and *B. juncea* (Indian mustard) suppressed radial growth of the potato fungal pathogens *Helminthosporium solani* and *Verticillium dahliae* on culture media (Olivier 1999). Green manures may also suppress fungal disease by promoting populations of beneficial microorganisms (McGuire 2003). However, 2-phenethyl-isothiocyanate applied to soils inhibited the nitrifying activity of nitrifying bacteria (Bending and Lincoln 2000). Mustards

and related cover crops can also suppress weeds. In Nebraska, mustard species and rape used as a green mulch in soybeans reduced weed biomass by 40 percent 4 weeks after emergence of soybeans and by 49 percent 6 weeks after emergence (Krishnan et al. 1998). Petersen et al. (2001) also observed suppression of weed germination by isothiocyanates in the soil following a turnip-rape mulch.

The potential for inhibition of weed growth is not always clear. Norsworthy et al. (2005) demonstrated variability of glucosinolate content and weed-suppressive ability of two mustard cover crops, *B. juncea* and *S. alba*. Allyl isothiocyanate concentrations equal to those released by *B. napus* did not inhibit growth of *Medicago sativa* (L.) (Fabales: Fabaceae), and *B. napus* showed no allelopathic interference to *M. sativa* (Choesin and Boerner 1991).

Mustard species rich in glucosinolates that produce isothiocyanates have been used to control soil-borne nematodes (Chitwood 2002). Turnip and mustard crops, in rotation with sugar beets, *Beta vulgaris* (L.) (Caryophyllales: Amaranthaceae), were effective at reducing soil populations of sugar beet nematode, *Heterodera schachtii* (Schmidt) (Tylenchida: Heteroderidae), and had a more positive effect on sugar beet yield than standard application of aldicarb (Koch 1991). The pesticidal properties of glucosinolate-producing plants can be enhanced by choosing plants with isothiocyanates of higher molecular weights or greater lipophilicity (Borek et al. 1998). Broccoli, *Brassica oleracea* (L.), can be an effective biofumigant against root knot nematode (*Meloidogyne incognita*) (Tylenchida: Heteroderidae) (Roubtsova et al. 2007). Broccoli-amended soils supported significantly lower pest nematode populations than control soils. Direct effects of soil incorporation of broccoli tissue, not indirect volatiles from the broccoli, lowered the nematode population (Roubtsova et al. 2007).

Relatively few studies have focused on the effects of glucosinolates and isothiocyanates on arthropods. Peachey et al. (2002) found that mustards were less effective than cereal cover crops in reducing the numbers of a pest symphylan, *Scutigereilla immaculata* (Newport) (Symphyla: Scutigerellidae). Sowing a mustard cover in a broccoli main crop has reduced aphid populations (Kloen and Altieri 1990) (although this may not be related to the glucosinolate-isothiocyanate system described above). Of a variety of cover crops that were tested in apple orchards in Australia to reduce apple pests and enhance natural enemies, *Sinapis alba* produced the most biomass but was not associated with any increase in beneficial arthropod abundance (Bone et al. 2009).

Extraction of isothiocyanates, particularly allyl isothiocyanate, isolates the toxic breakdown products that can then be used as biologically derived fumigants. In a study of the insecticidal fumigant properties of plant essential oils against the larval stage of *Lycoriella ingenua* (Dufour) (Diptera: Sciaridae), horseradish, *Armoracia rusticana* (G. Gaertn., B. Mey. & Scherb.), oil was among the most biologically active. Allyl isothiocyanate was the most toxic of the chemicals extracted from horseradish (Park et al. 2006). The insecticidal properties of allyl isothiocyanate from horseradish were also effective against four species of stored product pests and proposed as effective alternatives to methyl bromide and phosphine (Wu et al. 2009). Allyl isothiocyanate also functions as a chemical expellant of earthworms in soil and may be effective as an alternative to formalin (Zaborski 2003).

Despite the attention given to beneficial aspects of mustard species grown as cover crops, few studies have investigated the effects of mustards on non-target organisms. In studies of entomopathogenic nematodes, *Steinernema* spp. were sensitive to incorporation of mustard

(Henderson et al. 2009, Ramirez et al. 2009), and the nematodes' biocontrol effectiveness is reduced.

Arthropod Biodiversity in Agroecosystems

The effects of agricultural practices on non-target arthropods are of interest in integrated pest management. Many practices may have unintended effects on beneficial organisms, and carabid beetles, mites and springtails are frequent subjects of investigation because they are valuable in biotic control of pests or decomposition.

Ground Beetles (Coleoptera:Carabidae): Biology and Ecology in Agroecosystems

Ground beetles are generalist predators of arthropods and are considered beneficial insects in agroecosystems. Nearly all are active above-ground predators, and their prey consists mostly of other arthropods, but some species are herbivorous and eat seeds of weedy plants (Tooley and Brust 2002). They are holometabolous insects whose larval and pupal stages occur in the soil where the larval stages are active predators. Most carabids are nocturnal, but some are diurnal (Lovei and Sunderland 1996). Since the intensification of farming practices in the 1950s, carabid abundance and diversity have been declining (Holland 2002). Carabids are increasingly a focus of conservation efforts in agroecosystems (Holland 2002). Two carabid species, *Pterostichus melanarius* (Illiger) and *Harpalus erraticus* Say, prey on the pest millipede *Cylindroiulus caeruleocinctus* (Wood) (Diplopoda: Julidae), and *P. melanarius* coexists spatially and temporally with this millipede in sweet potato and carrot plantings in Ontario (Brunke et al. 2009). In studies of integrated pest management in Australia, higher incidence of predatory arthropods, including numerous carabids, resulted in increased mortality of *Plutella xylostella*

(L.) (Lepidoptera: Plutellidae) (Furlong et al. 2004). In winter wheat in Germany, carabids and spiders (Lycosidae, Linyphiidae) have been reported to lower aphid populations (Lang 2003).

Carabid activity and density are affected by several environmental factors. Carabid activity is affected by differences in vegetation density, and in a modeling experiment, Thomas et al. (2006) found a significant number of beetles moved from habitats with high vegetation density to habitats with low vegetation density. In agroecosystems, carabid assemblages show strong yearly variability (O'Rourke et al. 2008). O'Rourke et al. (2008) found that carabid activity and density were higher in a low-input 4-year rotation system than in a conventionally managed 2-year corn-soybean rotation. Carabid activity and density were measured in three cropping systems under various management regimes: reduced tillage, fall-sown cover crop, organic manure, and straight cutting of a wheat crop. Activity and density were higher in diverse systems than in conventionally managed systems, although crop type had a stronger effect on carabid assemblages than management system (Bourassa et al. 2008). Lepidoptera-specific *Bt*-corn does not significantly affect carabid assemblages (Floate et al. 2007, Toschki et al. 2007, Priestley and Brownbridge 2009), and carabid beetles readily feed on lepidopteran larvae containing the *Bt* toxin in laboratory assays (Meissle et al. 2005). Imidacloprid seed treatments in corn did not result in significantly different numbers of carabids in pitfall traps in treated versus untreated fields (Albajes et al. 2003). Cypermethrin and demeton-*S*-methyl applied to winter wheat fields in England had only short-lived effects on carabids and other predatory arthropods (Shires 1985).

Carabids readily disperse and respond quickly to environmental disturbance. A mark-and-recapture study of the movement of *Abax ater* (= *Abax parallelepipedus* Piller & Mitterpacher) in France demonstrated that beetles readily move between habitats, and when

placed in cultivated land tended to move toward woody habitats (Martin et al. 2001). Not all carabid species show the same response to tillage practices. In northwestern Idaho, carabid species richness and diversity were higher in no-till systems, whereas abundance was higher in conventionally tilled systems because of the dominance of a single species, *Poecilus scitulus* L. (Hatten et al. 2007). Hatten (2007) found that carabid species responded differently to tillage, depending on their ability to disperse. Rotary and moldboard tillage reduced carabid weed seed predators by 52 percent and arthropod predators by 54 percent in a field experiment in Maine, but carabid density in chisel-plowed plots was similar to the undisturbed control except for one species, *Pterostichus melanarius* Illiger (Shearin et al. 2007).

Collembola: Biology, Biodiversity and Ecological Roles

Springtails (Hexapoda: Collembola) are cosmopolitan and are often abundant in soils and litter (Christiansen and Bellinger 2003). They feed mostly on fungal spores and decaying vegetation, although some are predaceous (Christiansen and Bellinger 2003). Morphology is indicative of habitat, as surface-dwelling springtails have well developed color patterns and furcula; while soil-dwelling springtails have reduced or no eyes, reduced furcula, and weak pigmentation (Christiansen and Bellinger 2003).

Collembolan community structure is stable in late successional ecosystems, as species combinations are likely maintained by strong species interactions rather than climatic variability (Kuznetsova 2006). Kuznetsova (2006) found that community structure was much more stable in forest than meadow ecosystems. In the presence of increased predatory mite biomass, collembolan biomass remained stable, likely buffered by parthenogenic reproduction and short generation times (Taylor et al. 2010). Ponge et al. (2003) found a decrease in species richness

and total abundance of springtails along a land use gradient from forest soils to heavily cultivated field crops, with the most marked decrease in areas of rapid afforestation.

In a study of litter-dwelling springtails under four tree species in agroforestry plantings, Badejo et al. (1998) found that high soil moisture and low temperature encouraged springtail population growth, while low soil moisture and high temperatures due to lack of vegetative cover were negatively correlated to collembolan population growth. Badejo and Straalen (1993) and Badejo et al. (1998) found multiple peaks in populations of dominant collembolan genera throughout the year, and the authors attributed these peaks to iteroparous development.

Soil Mites: Biology, Biodiversity and Ecological Roles

Mites (Arachnida: Acari) in the order Mesostigmata (Acari: Parasitiformes), and suborders Prostigmata (Acari: Trombidiformes), Endeostigmata (Acari: Sarcoptiformes), and Oribatida (incl. Astigmata) (Acari: Sarcoptiformes) are found in almost every soil ecosystem, and high densities are associated with greater amounts of organic matter (Barbercheck et al. 2009). These mites are among the most abundant arthropods found in soil environments, and they exhibit a wide variety of life histories (Wallwork, 1970). In temperate forest soils, there may be upwards of 250,000 individuals per square meter, representing 100 mite families (OConnor 2003). In forest soils, fungus feeding oribatid mites had a positive effect on the recovery of the ecosystem after a disturbance by dispersing fungal spores and replenishing the microbial community (Maraun et al. 1998). Species richness and abundance decrease with soil depth in forest organic layers (Berg et al. 1998). Mites of the suborder Oribatida are mainly saprophores and detritivores, and their most important ecological function is comminution of organic matter (OConnor 2003). Typically, oribatid mites are *K*-strategists, that is, they have

long life spans, sometimes spanning several years, produce relatively few offspring, have relatively low mobility, and are common in stable environments such as boreal forest floors (OConnor 2003). For these reasons, oribatids are effective indicators of disturbance, and Behan-Pelletier (1999) proposed using the Oribatida (incl. Astigmata) as bioindicators for agroecosystems. Behan-Pelletier (1999) also proposed inclusion of the Astigmata in biodindication studies because, in contrast to most other oribatids, they are characterized by high fecundity and short lifespans, and, in some taxa, an effective dispersal life stage, the deutonymph (OConnor 2003).

Many factors influence oribatid populations. Densities of oribatids were positively correlated with soil moisture in forest soils at a test site in Africa, and the highest densities of oribatids were found in the more stable 5 cm top layer of soil than in litter layers (Badejo and Akinwale 2006). In a nationwide survey of soil invertebrates in Great Britain, oribatids favored undisturbed sites and soils with high organic content (Black et al. 2003). In an ecosystem with experimentally manipulated levels of microarthropod biomass, oribatid mites were found to be the least affected by mite predators (Taylor et al. 2010).

Mesostigmatid mites include free-living predators and parasites of other metazoans. Mites in the cohort Gamasina are more often encountered in soil environments than other mesostigmatid mites and are found mostly beneath the litter layers (Krantz and Ainscough 1990). Prey may consist of nematodes, springtails, mites, annelids, and insect eggs (Krantz and Ainscough 1990) (Koehler 1999). Gamasine predators are either active foragers or passive trappers (OConnor 2003). Abundance of mesostigmatid mites depends on seasonality and locality (Krantz and Ainscough 1990).

Life history strategies vary considerably in the prostigmatid mites, which include free-living saprovores and predators, obligate plant feeders, specialized fungus feeders, and parasites of vertebrates and invertebrates (Kethley 1990). Feeding preferences can differ among species within individual families (Kethley 1990). Many species of prostigmatid mites are economically important pests of stored products and crops, and some are medically important. In a study on the vertical distribution of mites in soil in a conventional tillage and no-till ecosystem in Georgia, only prostigmatid mites were numerous at all depths (0-24.5cm) (Perdue and Crossley 1990).

Sampling and Analyzing Soil Arthropod Populations and Communities

Methods for sampling and analyzing soil arthropod populations and communities vary depending on the taxa of interest. Selection of sampling methods depends on the habits and habitat of the animal in question, and there are efficiencies and inefficiencies associated with all methods. Analyses are also dependent on the experimental goals of individual studies.

Pitfall traps intercept ground-dwelling animals, usually without the use of an attractant, and are used to provide relative density estimates (Southwood and Henderson 2000, Ausden and Drake 2006). They are used extensively in studies of carabid biodiversity (Thomas et al. 2006, Liu et al. 2007), but catches indicate arthropod activity rather than absolute density, and results are influenced by environmental conditions. Light traps are also used to assess carabid biodiversity, but samples are biased toward species with high dispersal capabilities (Liu et al. 2007). Because of the drawbacks of using pitfall catches to estimate carabid biodiversity, mark-and-recapture methods are necessary to make absolute estimates of population size (Thomas et al. 2006). Thomas et al. (2006) also found that densities in adjacent treatments in a single field

trial are not independent of each other because of significant movement between treatments, especially if there is a vegetation density gradient.

Numerous methods are used for extraction of fauna from soil and litter, and each has benefits and drawbacks (Macfadyen 1962). A method commonly used in studies of soil microarthropods relies upon a behavioral or dynamic technique for obtaining absolute population measurements. Soil cores or litter samples are placed into a Berlese-Tullgren funnel, which establishes a humidity gradient that forces animals downward and into a vessel filled with a preservative (Macfadyen, A. 1962). This method is known as dry-extraction. A contrasting approach is wet-extraction, in which samples are flooded with water, stirred, and animals are extracted with a hydrocarbon (usually hexane or kerosene) (Southwood and Henderson 2000). Dry extraction is biased toward active life stages of arthropods and will not extract eggs or other immobile stages (Southwood and Henderson 2000), whereas soil washing techniques recover all arthropod life stages but are much more labor-intensive. Edwards (1991) assessed the efficiency of all extraction methods for soil mesofauna and concluded that the use of a Macfadyen modified high-gradient extractor is suitable for springtails and mites from arable land. This extractor is based on the Tullgren method of arthropod extraction in that it uses a light bulb placed above a sample to drive the animals downward into a collection vessel, but it optimizes the temperature and humidity gradients in funnels to improve the efficiency of extraction (Macfadyen 1953).

Numerous methods are used for quantifying and analyzing diversity and community composition, and many are indices based on species presence and abundance. These indices are used to transform multiple measures of abundance (counts) into a single figure suitable for univariate statistical analysis. Some of the more frequently used diversity indices are the

Shannon-Wiener function (H') and the Simpson index (D). The Shannon-Wiener function is defined as:

$$H' = - \sum_{i=1}^S (p_i \ln p_i)$$

where p_i is the proportion of individuals in the i^{th} species and S is the total number of species (Shannon, 1948). This index accounts for both species richness and evenness, and each addition of unique species increases the value of the index (Southwood and Henderson 2000).

The Simpson index is defined as:

$$D = 1 - \frac{\sum_{i=1}^S n_i(n_i - 1)}{N(N - 1)},$$

where n_i is the number of individuals in the i^{th} species, S is the total number of species and N is the total number of individuals in the sample. The Simpson index, heavily influenced by dominant species, evaluates the probability that a second individual drawn from a population is the same species as the first (Southwood and Henderson 2000). Species accumulation and rarefaction curves are analytical methods for comparison of species richness, because these measures standardize by area and sampling effort (Gotelli and Colwell 2001).

The principal response curve is a multivariate method for analyzing time-dependent changes in an entire community to an exogenous stressor (experimental treatment) (Van den Brink and Ter Braak 1999). The principal response curve is based on redundancy analysis and was developed to depict responses dependent on time without a cluttered ordination plot. The statistical model for the principal response curve is:

$$Y_{d(j)tk} = y_{0tk} + b_k c_{dt} + \epsilon_{d(j)tk}$$

where $Y_{d(j)tk}$ is the abundance of species k in replicate j of treatment d at time t , y_{0tk} is the mean abundance of species k in time t in the control, $b_k c_{dt}$ is the model of the response pattern for each

species (where b_k is the species weight and c_{dt} is the least-squares estimate of the coefficients), and $\varepsilon_{d(j)tk}$ is a random error term. The significance of the model is tested using an F -test statistic. This analysis generates a model of community abundances over time, and the accompanying taxon weights allow a species-level interpretation of the model. A species with a positive weight is more likely to have a response that matches the model, whereas a species with a negative weight is more likely to have an opposite response; a species with a weight near zero either shows no response or the response is unrelated to the pattern of the curve (Van den Brink and Ter Braak 1999). Van den Brink et al. (1997) used principal response curves to describe the response of aquatic invertebrates over time to variable levels of the insecticide chlorpyrifos, but the applicability of this method extends beyond aquatic ecotoxicology. Moser et al. (2007) used principal response curves to study the effects of carbendazim on enchytraeids (Annelida: Oligochaeta) in soil ecosystems.

A range of approaches to the identification of taxa have been used in ecological studies. Many agroecological studies evaluate soil taxa as morphotypes instead of compiling extensive species lists. Adl et al. (2006) evaluated the recovery of biodiversity of soil biota in conventionally tilled and no-till cotton (*Gossypium hirsutum*) fields in Georgia. They concluded that using morphotypes was adequate to elucidate differences in diversity between communities when overall abundance data alone did not provide adequate resolution. Adl et al. (2006) evaluated mite taxa at the ordinal, subordinal, and family levels and were able to detect differences in diversity indices even at these levels of identification. However, many responses to experimental pressures may be species-specific, so the compilation of extensive species lists for community analysis can yield much more information than higher level taxonomic groupings alone. Responses of microarthropods to various organic manures were evaluated in Italy, and

each taxonomic group responded differently to the inputs; the authors concluded that these responses may be species-specific (Fratello et al. 1989).

Functions and Disruptions of Microarthropod Communities in Agroecosystems

Soil fauna perform essential functions in soil environments. Their roles include mobilization of nutrients such as nitrogen (Petersen 2000), decomposition of organic matter, nutrient cycling, bioturbation, and suppression of soilborne diseases and pests (Brussaard 1997). They also are linked to sustainability in agroecosystems (Brussaard et al. 2007). Much of the biodiversity in agroecosystems is in the soil, and below-ground foodwebs are directly related to the health of crops and reduced incidence of soil-borne diseases and pests (Brussaard et al. 2007). Berg (1998) found that increased abundance and biomass of soil fauna (mites, spiders, and springtails) coincided with the greatest rates of decomposition of litter in a Scots pine (*Pinus sylvestris* L.) forest. In the layer in which the greatest biomass of springtails and oribatid fungal browsers were found, fungal biomass was also the greatest. Collembola add an estimated 10 mg.m⁻² to the soil nitrogen flux from excretion and conversion of dead collembolan tissues, yet this is only a fraction of the contributions from earthworms (Annelida: Oligochaeta) (Petersen 2000). Soil fauna directly influence plant health because they consume and disperse mycorrhizal spores (Koehler 2000). Mycorrhizae enhance overall plant growth by improving nutrient absorption (Ray 2003). Oribatids and other organisms are important in calcium cycling and organic decomposition processes, as they are effective dispersers of bacteria and fungi important for decomposition (OConnor 2003). Microarthropod biomass significantly affects biomass of other soil fauna (such as enchytraeids and nematodes) through indirect competition so that the soil environment is able to buffer the effects of large increases in microarthropod biomass in the short term (Taylor et al. 2010).

Plowing or other tillage practices result in the greatest negative impact on soil mite populations (Koehler 1997), causing up to 50 percent reductions in population densities directly after tillage (Hülsmann and Wolters 1998). In general, undisturbed soil ecosystems have greater species richness of mites than do agricultural soils (Barbercheck et al. 2009). Reduced and no-tillage systems typically show greater biomass of soil fauna (Zwart et al. 1994; Koehler 1997). Badejo et al. (2004) found that soil mite densities recovered under organic management despite an initial decline due to mechanical disturbance for cultivation. In forest harvesting systems, Oribatid biodiversity is negatively affected when habitats are altered drastically, such as in controlled burns, but microhabitats are more predictive of differences in biodiversity under less intensive harvesting regimes (Déchêne and Buddle 2009). Abandoning agricultural practices on arable land increases soil mite density but not species richness (Gormsen et al. 2006). Mechanical and other disturbances in agroecosystems exert selection pressures for fast recolonization. Because of this, small, edaphic mesostigmatid species with rather high reproductive capacities tend to be selected because of their ability to survive plowing and tolerate fluctuations in microclimate in bare or sparse fields (Koehler 1997). Oribatid and prostigmatid mite abundances increased in a no-till system in Georgia despite drought conditions (Perdue and Crossley 1989). Not all studies show a negative relationship between tillage practices and microarthropod abundance. Reeleder et al. (2006) found that tillage had little effect on most microarthropod groups (including mites and springtails).

Cultivation practices also influence springtail populations. Soil tillage and mechanical disturbance were correlated with a 70 percent decrease in collembolan density in an organic crop rotation in Denmark, with a very marked population decrease in the first 10 cm of soil (Petersen 2000).

Other means of environmental disturbance also affect microarthropod populations. Collembolan populations decreased when organic matter was removed and vegetation controlled in a loblolly pine (*Pinus taeda* L.) plantation in North Carolina (Eaton et al. 2004). In a study of the impacts of livestock grazing on microarthrod communities in Alberta, Canada, abundance of prostigmatid mites was significantly greater than abundance of oribatids and mesostigmatids in a very heavily grazed pasture (Clapperton et al. 2002).

Applications of synthetic pesticides often have negative impacts on non-target microarthropods. The addition of chlorpyrifos to an experimental site reduced numbers of spiders and diversity of the collembolan community (Fountain et al. 2007). Fountain et al. (2007) found that while overall collembolan abundance increased in the experimental plots, 95 percent of the community was composed of one species, *Ceratophysella denticulata* Bagnall (Collembola: Hypogastruridae) and overall community diversity and evenness were drastically reduced. Frampton (2002) found that repeated applications of organophosphate insecticides reduced populations of collembolans within the test plots, but field-edge populations were not substantially affected. In wheat and mustard fields in West Bengal, India, mite and collembolan populations decreased under applications of aldrin, while there was only a temporary decline after applications of endosulfan and dimethoate (Joy and Chakravorty 1991). Mites were most sensitive to repeated applications of endosulfan and quinalfos soil treatments in cotton fields in Delhi, India, whereas collembolan populations showed no persistent significant change in response to the same treatments (Vig et al. 2006). Application of an herbicide mixture (nicosulfuron + atrazine) and chlorpyrifos in Viçosa, Brazil reduced collembolan and mite populations on the surface and mite and ant (Hymenoptera: Formicidae) populations in the soil (Pereira et al. 2005). Many studies of soil ecotoxicology have used a collembolan, *Folsomia*

candida Willem (Collembola: Isotomidae), as a model organism because of its cosmopolitan distribution in soils and its relative ease of culture in the laboratory (Fountain and Hopkin 2005). The International Standards Organization in 1999 issued a standardized protocol concerning the use of this organism in ecotoxicological studies (ISO 1999).

Not all synthetic inputs have obvious direct impacts on non-target communities. Little direct impact was found on collembolan or carabid communities in fields where *Bt* corn was grown in New England (Priestley and Brownbridge 2009). Al-Deeb et al. (2003) found that numbers of Prostigmata, Oribatida, Mesostigmata and Collembola were similar in plots of Coleoptera-specific *Bt*-corn expressing the Cry3Bb1 toxin and its untransformed isolate.

The functioning of above-ground ecosystem processes is linked to below-ground soil processes, and soil faunal communities are integral parts of below-ground processes (Huhta 2007). However, it is unclear if above-ground vegetative diversity is causative of below-ground faunal diversity, if faunal diversity is causative of vegetative diversity, or if these relationships are correlative only (Coleman and Whitman 2005). The use of leguminous cover crops in Brazil had a positive effect on oribatid mite density and activity, and each species of legume supported independent communities of oribatids (Badejo et al. 2002). Although generally there is little or no host-habitat specificity of soil mites linked to dominant plants in an ecosystem, Osler and Beattie (2001) concluded that the ecological effects of dominant plant species should be considered along with structure of their respective soil fauna communities. Soil mite communities under three tree species with varying ecological effects on the soil showed no significant compositional effects, but the relative abundance of dominant species varied significantly (Osler and Beattie 2001). Community composition of litter-dwelling oribatids was not affected by species richness of trees in a deciduous forest (Kaneko et al. 2005).

Research Goals

Prior work on the value of mustards as green manures and biofumigants has prompted expanded studies of their value as short-season cover crops for use prior to seeding main crops of cucurbits such as cucumbers and pumpkins. Most of this research has focused on the impacts of glucosinolates on weed seeds and plant pathogens in soils into which the mustards have been incorporated. Little or no previous research has focused on the impacts of mustards and glucosinolates on soil arthropods. Because carabid beetles, collembolans, and mites are very common beneficial organisms in the soils of agroecosystems, the research presented in this thesis examined their responses to the use of mustards as cover crops. I tested the following null hypotheses: (1) population densities of carabids, mites, and springtails are not altered by the use of mustard cover crops; (2) species diversity, indicated by species richness, the Shannon-Wiener function (H') and the Simpson index (D), within these groups is not altered by the use of mustard cover crops; and (3) overall community responses of the taxa investigated did not differ over time based on the use of mustard cover crops. The abundance of these groups and dominant species within each group were examined before, during, and after the seeding, growth, and incorporation of two mustard varieties (individually or in combination) and in plots where no cover crops were grown.

Materials and Methods

Field trials were done in 2008 and early 2009 at the University of Illinois Vegetable Crops Research Farm near Champaign, IL (N 40.092°, W 88.242°) in conjunction with studies of the impacts of soil incorporation of mustards used as early-season cover crops on cucumbers or pumpkins grown as the subsequent main-season crops. Brown (Indian) mustard, *Brassica juncea* (L.) Czern var Florida Broadleaf, and yellow (white) mustard *Sinapis alba* L. var Tilney (syn *Brassica hirta* Moench), were used. Plots were established in a randomized complete block design with three replicates in 2008. The four treatments were (1) no cover crop, (2) Tilney mustard, (3) Florida Broadleaf mustard, and (4) a mixture of Tilney and Florida Broadleaf mustards.

The field used for this study measured 86 x 102 m. Each plot (or replication of each treatment measured 19 x 30 m, and buffers between the plots were 3 or 6 m wide. In previous seasons, rotations of corn, *Zea mays* (L.), and soybean, *Glycine max* (L.), were grown in this field. No *Brassica* spp. cover crops or main crops had been grown on these plots in recent years.

The herbicide Treflan (trifluralin) was applied on 30 April at 1168 ml/hectare (1 pint/acre) and incorporated with a field cultivator to control weeds. The mustards were broadcast by hand on 21 May, and the plots were rolled the following day. Following approximately 6 weeks of growth, the mustards were mowed and incorporated into the soil on 2 July. Mean of dry weights of mustard biomass and total plant biomass in the cover-crop plots and no-cover-crop plots are presented in Appendix Table 1. The first planting of the cucurbit main crop (pumpkins/cucumbers) was made on 3 July, with a second planting following on 8 July. Because of significant crop loss from ground squirrel consumption of planted seeds, the

entire field was tilled on 18 July. Pumpkins were replanted on 29 July, and the cucumbers were replanted on 1 August. To control weeds, the herbicide Strategy (ethalfluralin + clomazone) was applied to all plots at 7010 ml/hectare (3 quarts/acre) on 1 August. Precipitation and temperature data recorded approximately 6 km from field site are presented in Appendix Table 2 for periods when sampling was done. The field was irrigated once on 18 August.

Pitfall traps and soil samples were used to assess arthropod populations. Insects were collected from pitfall traps during four sampling periods in 2008: 6–9 April, 10–12 June, 24–27 June, and 17–19 July. Pitfall traps were set and collected at approximately the same time in the morning to ensure equal representation of carabids active during night and day. Soil samples were collected in 2008 on 18 April, 2 June (1 week after planting of mustards), 29 June (shortly before incorporation of mustards), 18 July (2 weeks after incorporation of mustards and before the second tillage operation), and 11 September and in 2009 on 25 May.

A series of four pitfall traps (subsamples) were set per plot in a straight line along the middle, spanning the length (east to west) of each plot, for a total of 48 traps per sampling date (192 total traps). For each trap, a plastic cup (13 cm deep x 9 cm diameter) was set into the ground so that the lip of the cup was flush with the surface of the soil. Holes were cut with a cup cutter (Par Aide Products, Lino Lakes, MN), and the traps were covered with a piece of shingle (approximately 20 x 20 cm) propped up by nails to exclude vertebrates and excess water flow while still allowing free entry to surface-dwelling invertebrates. A flag was placed near each trap to ensure ease of rediscovery. Each trap was filled to a depth of approximately 2–3 cm with a 20% solution of propylene glycol in water and left for a period of 2–3 days. At the end of this period, the cups were removed from the ground and the contents were poured into glass mason jars. In the laboratory, the specimens were filtered from the propylene glycol mixture and

transferred to 70% ethanol for storage. Counts of carabid beetles collected in pitfall traps within each plot were summed and divided by the number of traps (excluding any traps that were flooded by rainfall during the sampling period) and expressed as numbers of beetles per trap per day.

Four soil cores (subsamples) were taken at random on each sampling date in each plot, resulting in a total of 48 cores per sampling date (288 total cores). The cores (approximately 11.5 cm in diameter x 6.5 cm deep) were dug using a stainless-steel cylinder (corer) with a sharp, tapered edge. The corer was then inverted and the contents emptied into a plastic container with a screened bottom (fine mesh cheesecloth between two layers of 1-cm hardware cloth) so that the soil surface rested on the screened bottom. This container was placed into a slightly larger plastic container with a lid for transportation to the laboratory for extraction.

The soil cores were processed in a modified high-gradient extractor (Macfadyen 1962; Merchant and Crossley 1970; Crossley Jr. and Blair 1991) for a period of 7-10 days. The samples were heated under a cover from above using 7-watt bulbs with baffles placed between samples to reduce escape and cross-contamination (E. Zaborski, Illinois Natural History Survey, personal communication). Light intensity, controlled by a rheostat, was raised gradually at daily intervals during the 7- to 10-day extraction period. The extractor was kept in a cooled ($\sim 15^{\circ}\text{C}$) environmental chamber maintained at $\sim 90\%$ relative humidity. Arthropods were collected directly into scintillation vials containing 75% ethanol for preservation until identification. Arthropods were sorted by hand using a Petri dish with a grid under a dissecting microscope. Carabids were identified according Lindroth (1974) and identifications were confirmed using reference specimens identified by Jonathan Lundren (North Central Agricultural Research Laboratory, Brookings, South Dakota) held at the Illinois Natural History Survey (Urbana-

Champaign, Illinois). Collembola were counted and identified according to Christianson and Bellinger (1980). Reference specimens were mounted on slides or photographed, and identifications were confirmed by Felipe Soto-Adames (Illinois Natural History Survey, Champaign, IL). Only adult springtails were counted and identified. Mites were counted and identified according to unpublished references by Walter and Beaulieu; Behan-Pelletier and Norton; Ochoa and Welbourn; (Summer Acarology Program, Ohio State University, Columbus). Larval and nymphal mites were counted for only certain groups. For mesostigmatids (Mesostigmata) and cunaxids (Prostigmata: Cunaxidae), immatures and adults were combined in counts. Immatures and adults of *Tectocephus* spp. (Oribatida: Tectocephidae), were counted separately. Reference specimens were mounted on slides for identification, and identifications were confirmed by David Walter (Royal Alberta Museum, Edmonton, Alberta, Canada), Frederic Beaulieu and Valerie Behan-Pelletier (Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada), Roy Norton (State University New York—College of Environmental Science and Forestry, Syracuse, New York), and Calvin Welbourn (Florida Department of Agriculture and Consumer Services, Division of Plant Industry, Gainesville, Florida).

All statistical analyses were conducted using R, version 2.10.1 (R Development Core Team, 2009). To assess differences in arthropod communities among treatments, analysis of variance (ANOVA), assessment of species richness (Southwood and Hendersen 2000), and analyses of diversity (Shannon 1948) were applied to data from each sampling date. Additionally, principal response curve analyses (Van den Brink and Ter Braak, 1999) were done to examine community responses over time in the plots where mustard cover crops were grown versus the control plots where no cover crop was planted. To test the null hypothesis that mustard treatments had no effect on arthropod densities, abundance data were analyzed using the

ANOVA general linear model. ANOVAs were completed for overall abundance and for dominant species of carabids, collembolans, and mites. The “vegan” package, version 1.17-2 of R (Oksanen et al., 2010) was used for analyses of species richness and diversity and for principal response curve analyses. To test the null hypothesis that mustard treatments had no effect on arthropod diversity within a sampling date, ANOVA was used to analyze means of indices of diversity and species richness. To test the null hypothesis that mustard treatments had no effect on arthropod communities over time, a principal response curve analysis was used. Statistical analyses were accepted as significant at the $P=0.05$ level. Because great abundance of few taxa skews the results for analysis with principal response curves, all measures of arthropod abundance were transformed ($\log [x + 1]$). Untransformed means of abundance are reported for select taxa. Assumptions of equal variance for ANOVAs were met by plotting and examining residuals.

Counts from pitfall traps within each plot were pooled and treated as one observation for analyses. Counts from the four soil cores from each plot (subsamples) also were pooled for analyses. To allow direct comparisons with other studies, mite densities were expressed on a per-square meter basis by dividing the number of mites per sample by the cross-sectional area of the soil core (0.011 m^2).

Results and Discussion

Carabidae

A total of 528 carabid beetles representing 8 genera were recovered from pitfall traps in all plots combined in 2008 (Table 1). Based on analyses of variance by ANOVA, overall abundance of carabids did not differ significantly among the cover crop treatments for any of the sampling periods (Table 2).

Anisodactylus santaecrucis Fabricius accounted for 54 percent of all carabids recovered, and *Poecilus chalcites* Say accounted for 32 percent. All other species were encountered infrequently. Two species were recovered only once, *Cicindela punctata* Olivier in the Tilney plots, and *Clivinia impressifrons* LeConte in the Florida Broadleaf plots. One species, *Crutacanthus dubius* Paliset, was recovered once in the Tilney plots and once in the plots where no cover crop was planted.

Means of counts of *A. santaecrucis* and *P. chalcites* are presented by date in Figure 1. (Standard deviations for these means are listed in Table 3.) These dominant species exhibited similar trends in mean abundance over the four sampling periods. In all the mustards and in the plots where no cover crops were grown, overall abundance declined between 12 June and 27 June, then increased again on 28 July following tillage and incorporation of all standing plants on 2 July (and prior to a second tillage operation before replanting cucumbers and pumpkins). Mean densities of the two dominant species of carabids did not differ significantly among treatments except for the 17-19 July collection, where counts of *P. chalcites* were greater in the

two treatments where Florida Broadleaf mustard had been grown than in plots where Tilney mustard or no cover crop had been grown (Table 3). These analyses indicate that the mustard cover crops did not influence the overall density of carabids or the densities of the two dominant carabid species.

Analyses of diversity (Shannon's H' and Simpson's D) and species richness are summarized in Table 4. There were no significant differences among treatments (specific mustard cover crops or no cover crop) in any of these indices of diversity and richness for any sampling date.

The P value for principal response curve analysis of carabid abundance was 0.73 (Figure 2). The model's lack of significance indicates that patterns of change in carabid communities over time could not be attributed to the cover-crop treatments. The cover-crop treatments accounted for 5 percent of the variation in observed activity. The trends represented by the model presented in Figure 2 suggest that in comparison with activity observed in the plots where no cover crops were grown, carabid activity increased over time in only the Tilney plots. The model suggests that the pattern of activity in the Florida Broadleaf and combination treatments decreased in comparison with activity in plots where no cover crop was grown. In principal response curve analyses, taxa with weights below the 0.0 line are more likely to show an opposite response than the model describes, and that response is concomitant with their position on the weight scale. The model suggests that *P. chalcites* decreased in activity in the Tilney plots over time (consistent with the graph of mean abundance) and that this trend was opposite of those in the other mustard treatments. The model suggests that *Anisodactylus santaecrucis* showed a similar pattern, decreasing in activity in the Tilney treatment. Because counts of carabids were transformed ($\log [x + 1]$) before analysis with the principal response curve,

impacts of rare species and dominant species were normalized, reducing the influence of the two dominant species on the overall model. The species least frequently recovered, *Harpalus pennsylvanicus* DeGeer, *C. dubius*, and *C. punctata*, have positive but low taxon weights, indicating that their patterns of abundance likely conformed to the model or were unrelated to the trends described by the principal response curve. The principal response curve describes an overall increase in activity of these taxa in the Tilney plots and an overall decrease in activity in the other mustard plots.

Because (as noted above) the model accounted for only a small portion of the variance observed in carabid activity, the trends represented in Figure 2 and discussed above cannot be interpreted as evidence that the mustard cover crops influenced carabid communities. Overall, the results of this principal response curve analysis (and the ANOVAs summarized in Tables 2-4) fail to support rejection of the null hypothesis that mustard cover crops do not influence carabid densities and community structure.

Collembola

A total of 32,036 Collembola representing 10 genera from five families were recovered from soil cores from all plots and sample dates combined (Table 5). Means of overall totals of collembolans per plot did not differ among treatments on any sampling date (Table 6).

One species, *Desoria trispinata* (Mac Gillivray) (Isotomidae), accounted for 82 percent of all individuals, with 10 other species comprising the remaining 18 percent. *Hypogastrura* spp., (Hypogastruridae) and *Entomobrya unostriata* Stach (Entomobryidae) also were collected on

most sample dates. One species of *Sminthurus* was recovered infrequently and found only in the Florida Broadleaf and Tilney + Florida Broadleaf plots.

Means of counts of three most common collembolans, *D. trispinata*, *Hypogastrura* spp., and *E. unostriata*, are presented by date in Figure 3 and compared by ANOVA in Table 7. Peak densities of *D. trispinata* occurred on 18 July, two weeks after tillage and incorporation of standing plants in all plots. In general, numbers of *Hypogastrura* spp. declined from spring, 2008, throughout the season and did not rebound to initial densities in spring, 2009. *Entomobrya unostriata* density increased on 18 July in the Florida Broadleaf + Tilney plots but not other plots. Means of counts of the three most common species of Collembola did not differ significantly among the cover-crop treatments for any of the sampling dates (Table 7).

Diversity indices (Shannon's H' and Simpson's D) and species richness values for collembolans are summarized in Table 8. Means of one or more of these indices differed significantly ($P < 0.05$) for three sampling dates – 18 April, 2008 (before cover crops were planted), 18 July, 2008 (approximately 2 weeks after standing plants were incorporated), and 25 May, 2009 (the following spring). Means of both H' and D were significantly different for 18 April 2008 (H' : $F=5.97$, $df=3$, $p=0.002$; D : $F=7.81$, $df=3$, $p=0.0003$). Pairwise t-tests indicated that means of these indices were significantly lower for the Tilney mustard treatment than the other treatments. Differences in means of species richness for this sampling date also were statistically significant ($F=2.95$, $df=3$, $p=0.04$). However, these differences were artifacts of prior field conditions because samples were collected before 2008 field operations began. Means of diversity indices and species richness also differed significantly among treatments on 18 July, 2008 (H' : $F=3.22$, $df=3$, $p=0.03$; D : $F=3.17$, $df=3$, $p=0.03$; S : $F=4.26$, $df=3$, $p=0.01$). For collections from 25 May, 2009, means of H' were significantly different (H' : $F=3.21$, $df=3$,

$p=0.03$), and pairwise t-tests indicated that diversity was greater in the plots where Florida Broadleaf mustard was grown in 2008 than in the plots where Tilney mustard was grown in 2008. Overall, these diversity indices indicate no consistent positive or negative effect of mustard cover crops on collembolan diversity or species richness.

Counts of five springtail taxa (*D. trispinata*, *Hypogastrura* spp., *E. unostriata*, *Folsomia diplophthalma* Alexson (Isotomidae), and *Isotoma* sp. 1 (Isotomidae) were combined with counts of mites for principal response curve analysis. That analysis is presented and discussed following the results of mite sampling.

Mites

A list of all species encountered, but not necessarily enumerated, is presented in Table 9. A total of 11,275 mites were identified from 31,798 total mites recovered from soil cores in 2008 and 2009 (Table 10). Most of the unidentified mites were prostigmatids, and because of their life histories and dispersal, they were not included in analyses of diversity or species richness. Identification concentrated on oribatids, and 14 species of Oribatida were recovered. The most frequently recovered oribatid was *Hemileius* sp. 1 (Scheloribatidae), and it accounted for 13 percent of all mites identified. Astigmatine mites accounted for 19 percent of identified mites. High densities of prostigmatid and astigmatid mites are found in disturbed systems. Other frequently encountered taxa were *Oppeia nova* Oudemans, *Speleorchestes* spp. and an *Enarthronota* sp. 1, which accounted for 12, 11, and 11 percent of identified mites, respectively. One mite, Galumnidae sp. 1, was found only once from the Tilney mustard treatment.

Means of overall mite density (and standard deviations) are presented by date in Table 11. Mite densities were significantly greater in plots where Tilney was planted than in plots where no cover crop was planted for 29 June ($F=4.18$, $df=3$, $P=0.01$), 08 July ($F=5.145$, $df=3$, $P=0.004$), and 11 September ($F=4.12$, $df=3$, $P=0.01$). Most of the mites extracted from soil cores were astigmatid and prostigmatid mites, which have high dispersal rates and quickly colonize ephemeral resources, and these were all sampling dates when organic matter was abundant.

Mean of counts of dominant taxa are plotted over time in Figure 4. *Hemileius* spp. peaked on 18 July in the plots where mustard cover crops had been grown. *Oppiella nova* populations tended to drop on 2 and 29 June (before standing plants were incorporated) and increase later in the season. *Tectocephus* spp. densities peaked on 18 July after tillage and incorporation of standing plants. *Oppiella nova* and *Tectocephus* spp. are commonly encountered in agroecosystems (Behan-Pelletier 1999). Densities of *Speleorchestes* spp. peaked in all treatments on 29 June prior to tillage and incorporation. Mesostigmatid mite populations were low during the spring and early summer sampling dates in 2008 but showed a dramatic increase on 18 July, then decreased for the rest of the season and on 25 May 2009. Cunaxid mites showed a similar population trend as the mesostigmatid mites.

Means of counts of dominant mite taxa (Table 12) did not differ significantly among treatments except on 18 July when cunaxid mites were more numerous in the plots where Tilney mustard had been grown than in the plots where no cover crop was planted (Table 12; $F=2.97$, $df=3$, $p=0.04$). Cunaxid mites are predatory and their peak densities coincided with a peak in overall populations of springtails. It is unclear, however, whether the peak in cunaxid densities

represented a numerical response to springtail density or a seasonal trend related to other available prey.

Summaries of diversity analyses (Shannon's H' and Simpson's D) and species richness for mites are presented in Table 13. For the 18 April 2008 collections, Shannon's H' indicated significantly greater diversity in plots where Tilney + Florida Broadleaf were to be planted than in plots where Tilney alone was to be planted (H' : $F=6.17$, $df=3$, $p=0.001$). Because this sampling date preceded field operations in 2008, clearly this was an artifact of prior conditions. On 29 June 2008, Shannon's H' indicated significantly greater diversity in the Tilney plots than in the plots where no cover crop was grown ($F=4.44$, $df=3$, $p=0.009$). Simpson's D did not differ significantly among treatments on any sampling date. The only significant differences in species richness were found for the same two sampling dates that Shannon's H' values were significant (18 April 2008: S : $F=2.96$, $df=3$, $p=0.04$; 29 June 2008: S : $F=4.39$, $df=3$, $p=0.009$).

The combined collembolan and mite community was examined by the principal response curve analysis (Figure 6). Thirty eight percent of the variance in the dataset was captured by the model, and the P value for the resulting model 0.53. The model's lack of significance indicates that patterns of change in these soil arthropod communities over time could not be attributed to the cover-crop treatments. The cover-crop treatments accounted for 4 % percent of the variation in observed activity. To allow clear presentation of the results, taxon weights were indicated in Figure 4 if the cumulative log abundance of the taxon, summed for all treatments and sampling dates, was greater than 100. The trends represented by the model presented in Figure 5 suggest that in comparison with densities observed in the plots where no cover crops were grown, springtail and mite densities show initial differences between communities in the Tilney and Florida Broadleaf plots and Tilney + Florida Broadleaf plots. Overall collembolan and mite

densities decreased by 2 June in the Tilney + Florida Broadleaf plots but increased in the others (relative to the control). After incorporation of the mustards, the extent to which collembolans and mites were more numerous in the mustard plots (in comparison with the control) declined. According to the model, taxa with higher taxon weights (*Oppiella nova*, *Entomobrya unostrigata*) increased during the period of mustard growth in all treatment plots except for the combination treatment, and then decreased in the sampling periods after incorporation.

Conclusions

Samples collected in 2008 and 2009 provided an inventory of carabids, springtails, and mites in plots where mustard cover crops were grown and in plots where no cover crop was planted. The lists of taxa collected within each group serve as a record of their seasonal occurrence at this site. There were few or no differences in overall densities of these groups or densities of dominant taxa within each group in plots where mustard cover crops were grown and plots where no cover crop was planted. Similarly, measures of diversity and analyses of community responses over time did not differ or differed only rarely between plots where mustard cover crops were grown and plots where no cover crop was grown. Based on this limited study, the use of mustard cover crops for other beneficial reasons seems unlikely to negatively influence these groups of soil arthropods.

Figure 1. Abundance of dominant carabid species by date in plots where mustard cover crops were planted and in plots where no cover crops were planted in 2008. Mustards were seeded on 21 May, and all plots were tilled on 2 July. Vertical lines indicate mustard incorporation on 2 July.

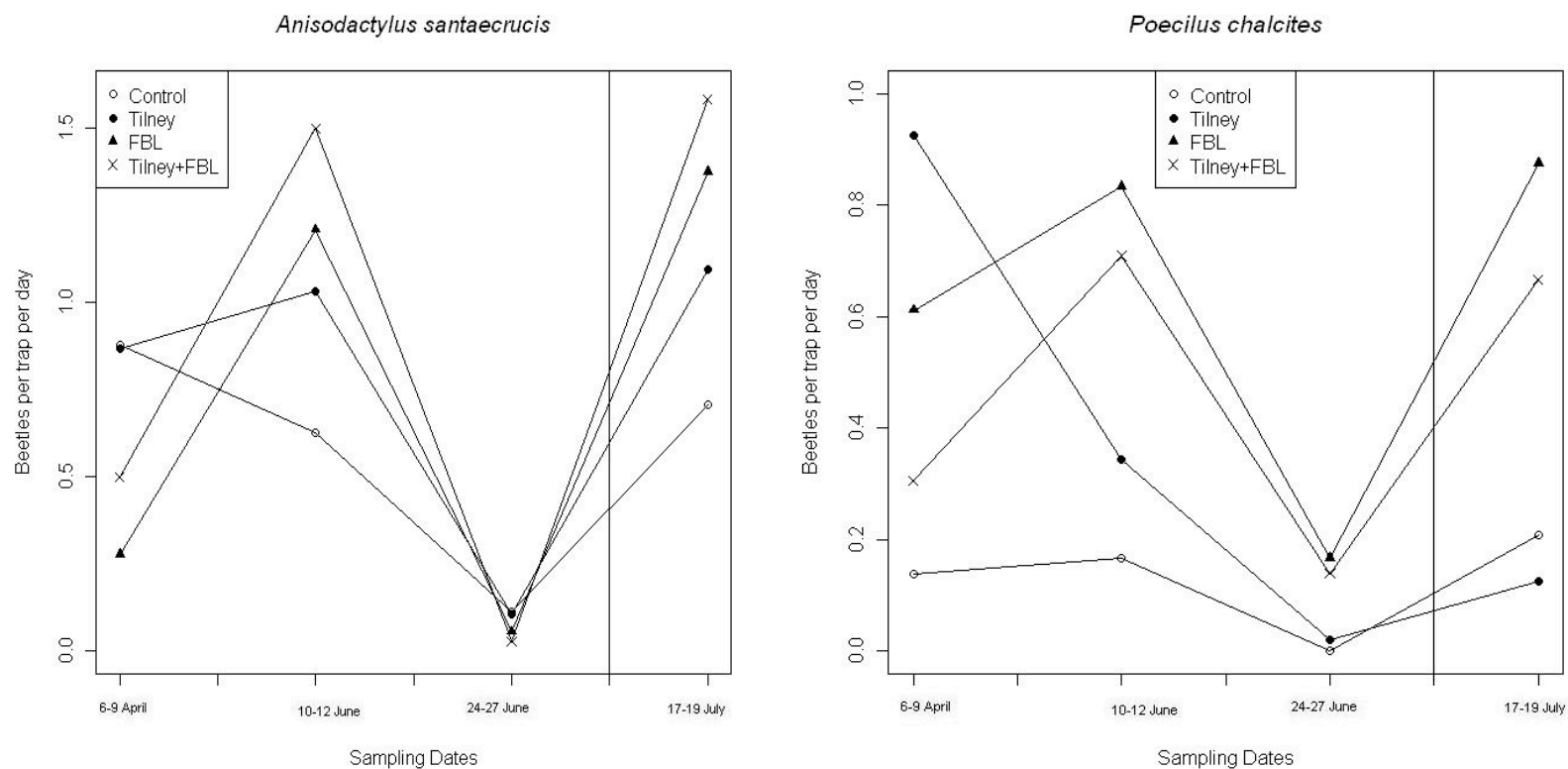


Figure 2. Principal response curve showing multivariate community responses in repeated observation design. Carabid community responses in the mustard cover crops are plotted against a control placed at 0 for the plots where no cover crop was planted. Mustards were seeded on 21 May, and all plots were tilled on 2 July. Counts were $\log(x + 1)$ -transformed prior to analysis. Taxon weights are plotted on the right axis, and they correspond to the PRC.

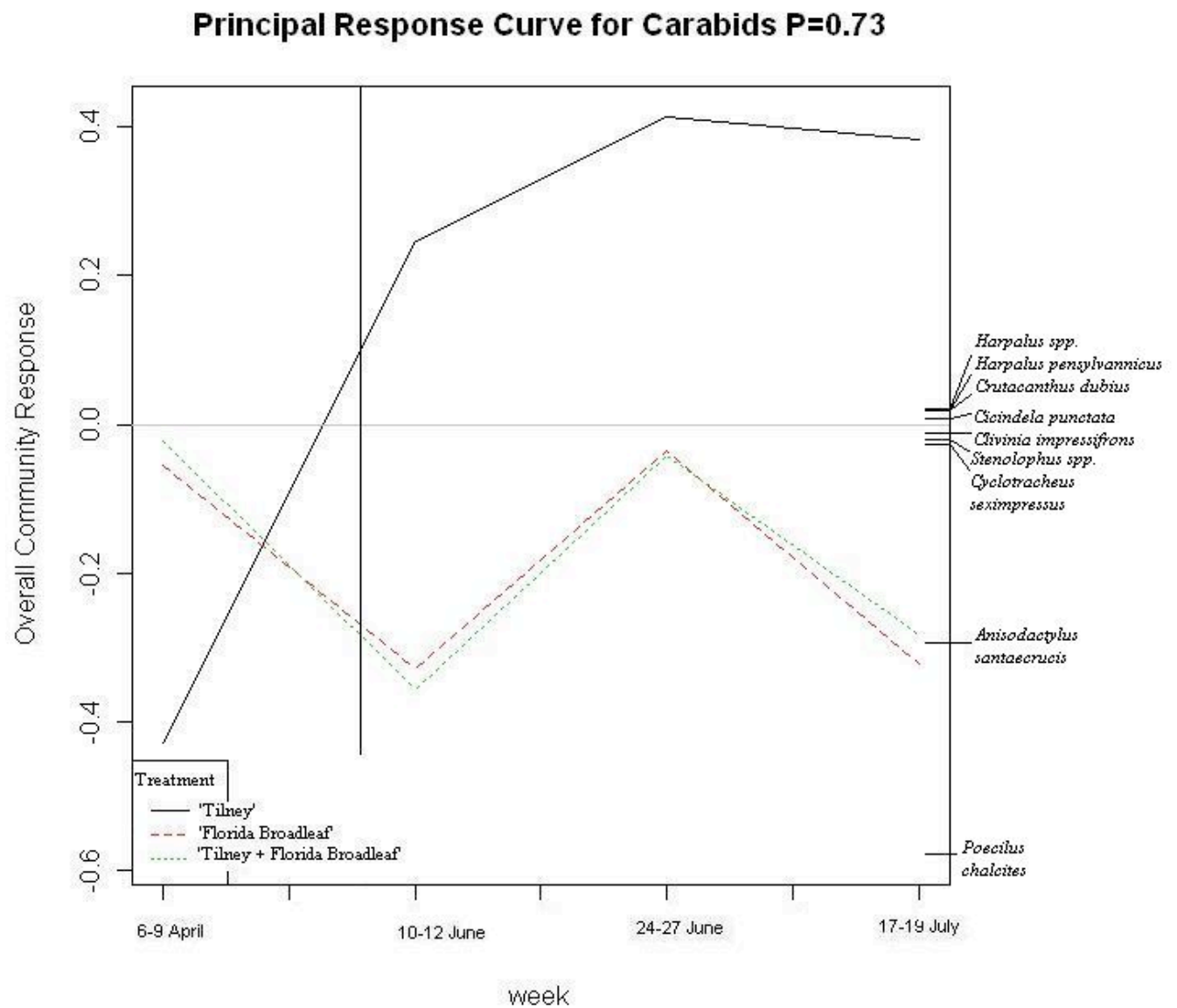


Figure 3. Abundance of the most common collembolan species by date in plots where mustard cover crops were planted and in plots where no cover crops were planted in 2008. Mustards were seeded on 21 May, and all plots were tilled on 2 July and 28 July. Vertical lines indicate mustard incorporation on 2 July.

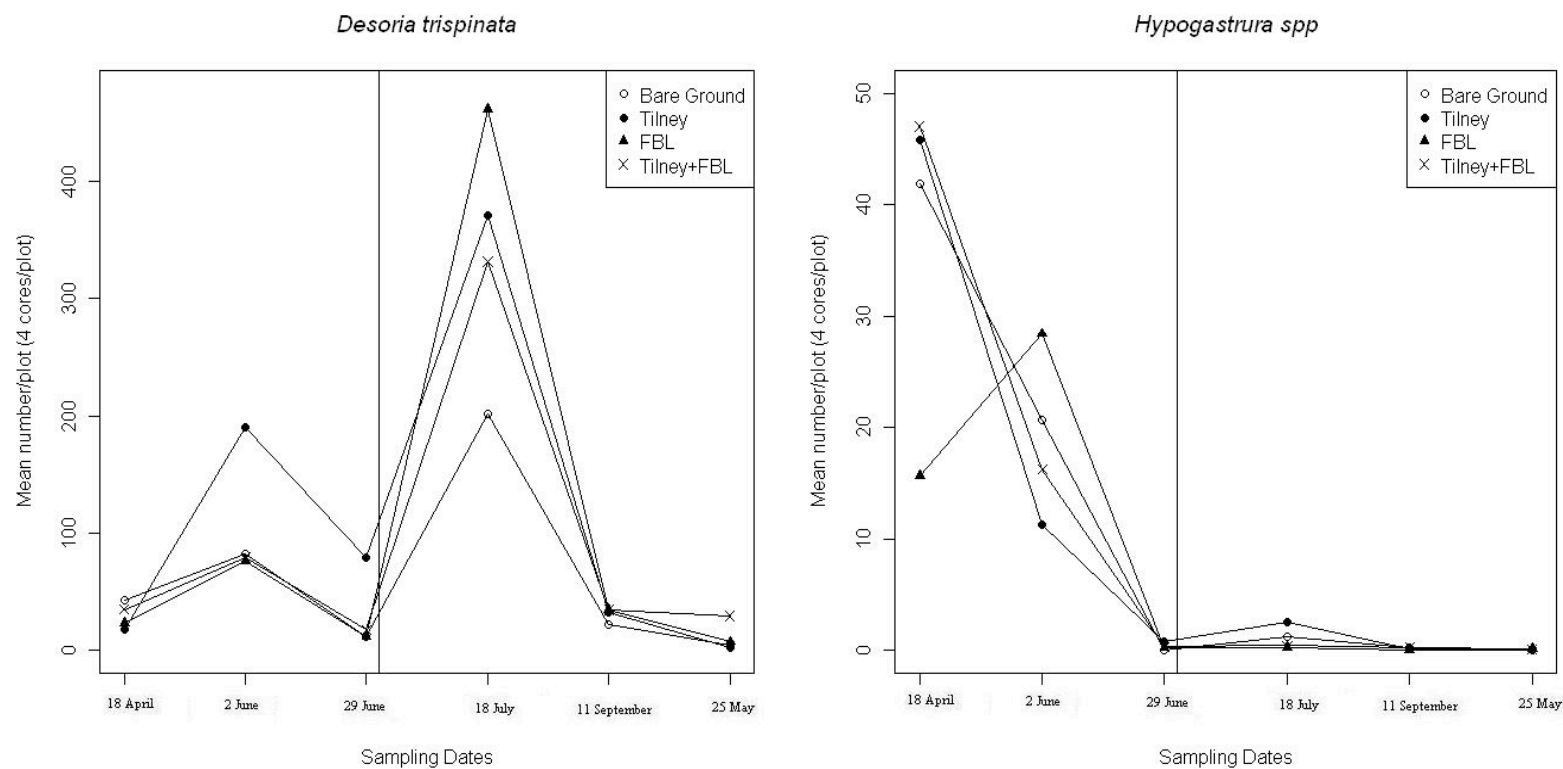


Figure 3 continued.

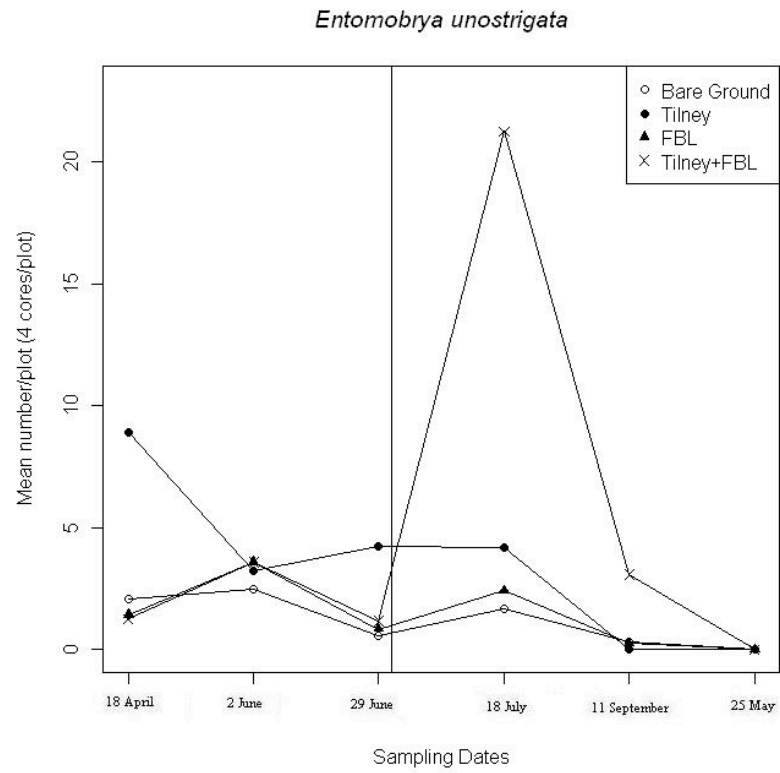


Figure 4. Abundance of selected mite taxa by date in plots where mustard cover crops were planted and in plots where no cover crops were planted in 2008. Mustards were seeded on 21 May, and all plots were tilled on 2 July 28 July. The vertical line indicates mustard incorporation on 2 July

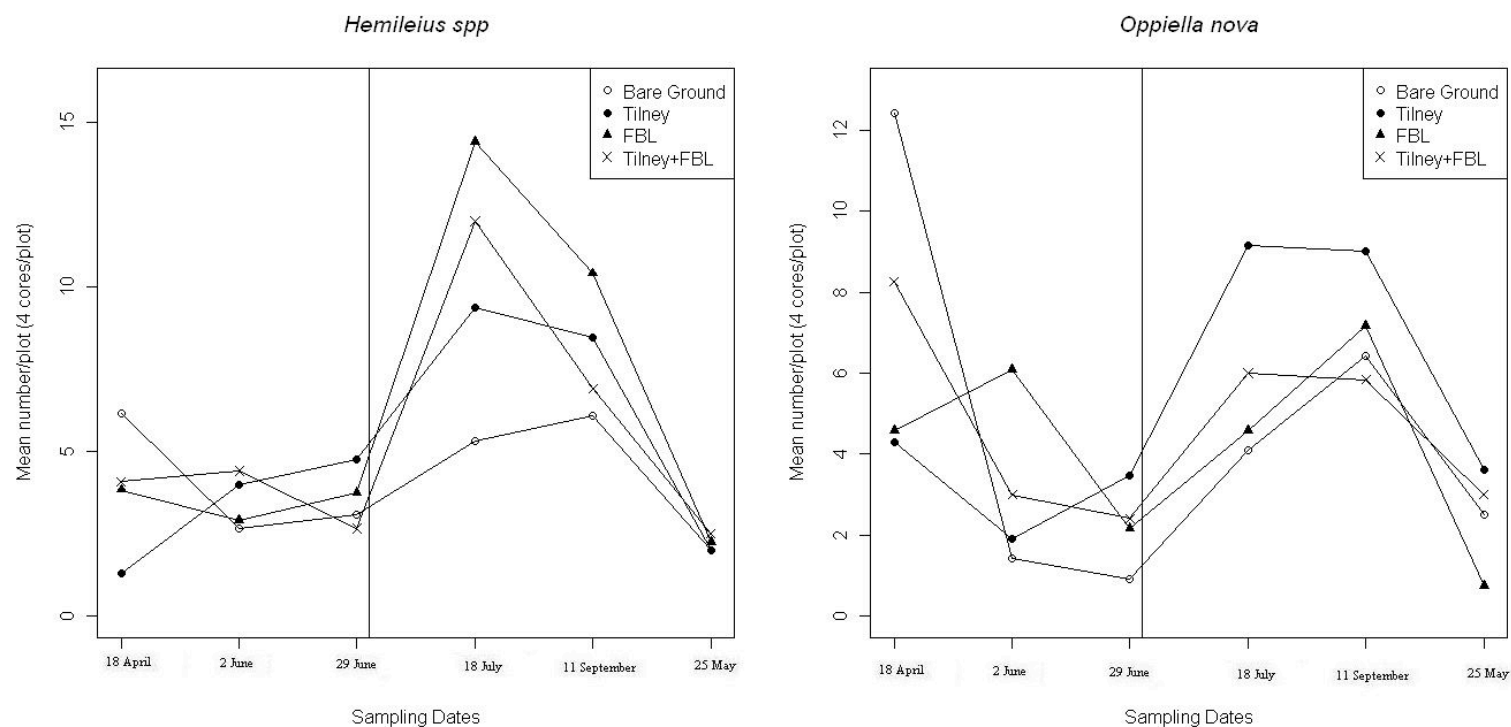


Figure 4. continued.

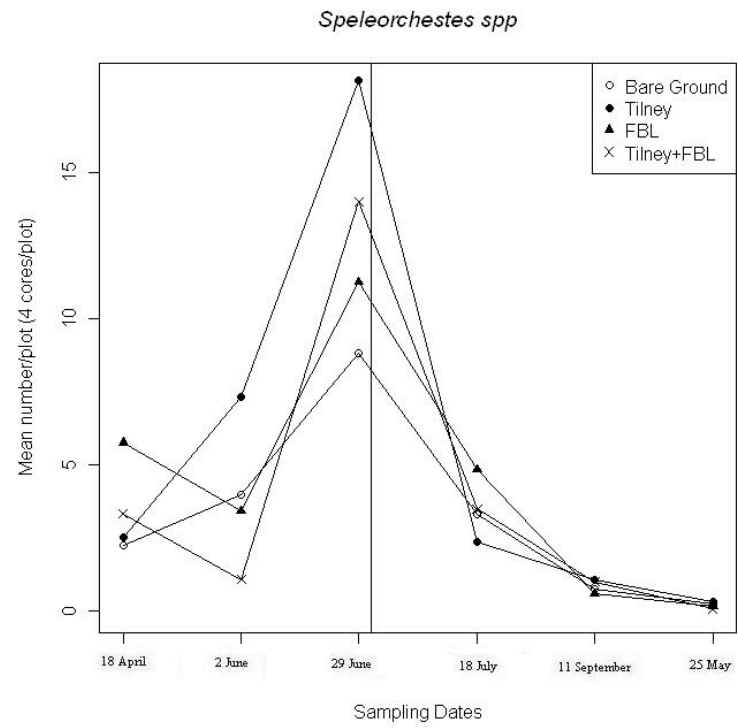
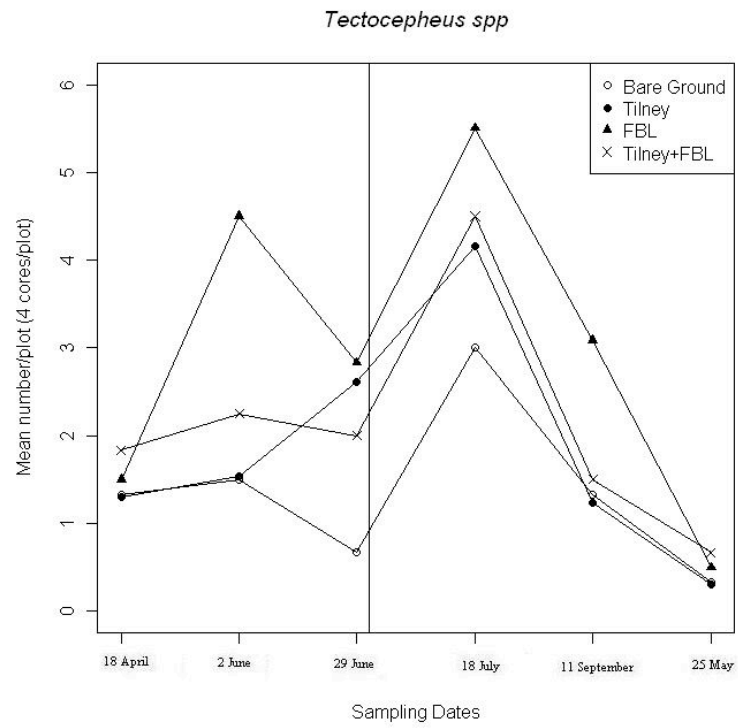


Figure 4. continued.

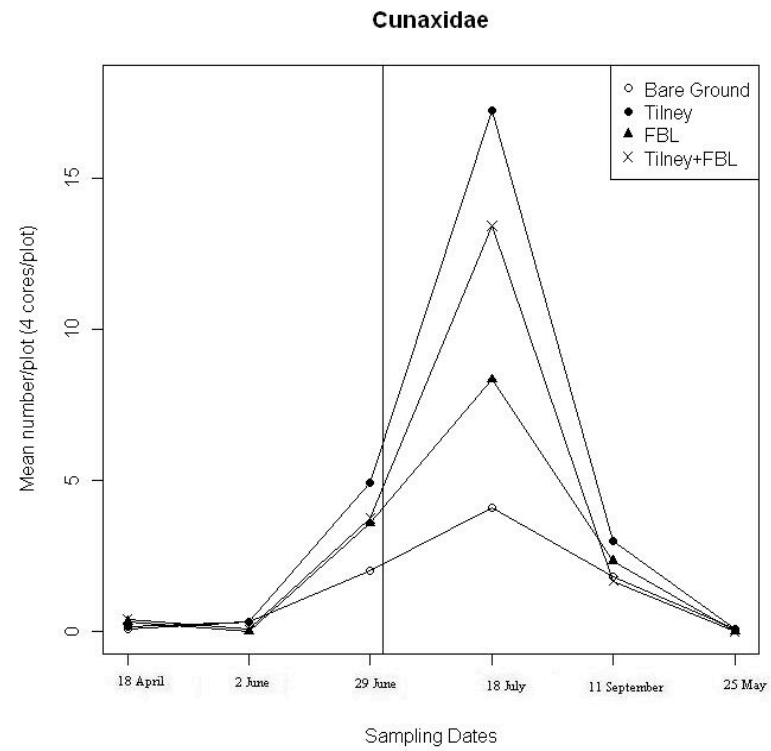
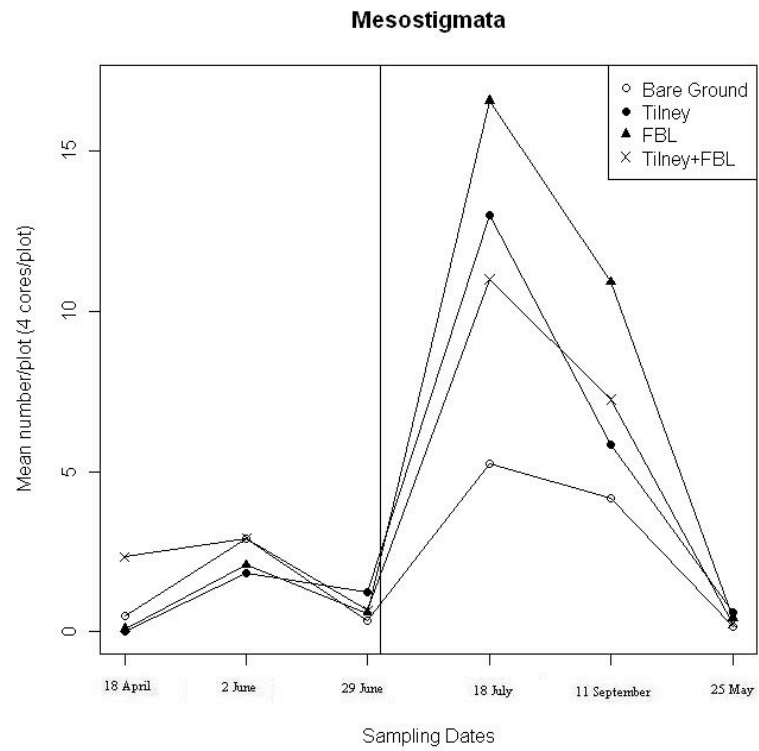


Figure 5. Principal response curve showing multivariate community responses in repeated observation design. Collembolan and mite community responses in mustard cover crops are plotted against a control placed at 0 for plots where no cover crops were planted. Mustards were seeded on 21 May, and all plots were tilled on 2 July and 28 July. Counts were $\log(x + 1)$ -transformed prior to analysis. Taxon weights are plotted on the right axis, and taxon weights with a cumulative log abundance of > 100 are plotted. (R-‘vegan’). The model is considered significant at $p = 0.05$.

Principal Response Curve for Total Microarthropods P=0.53

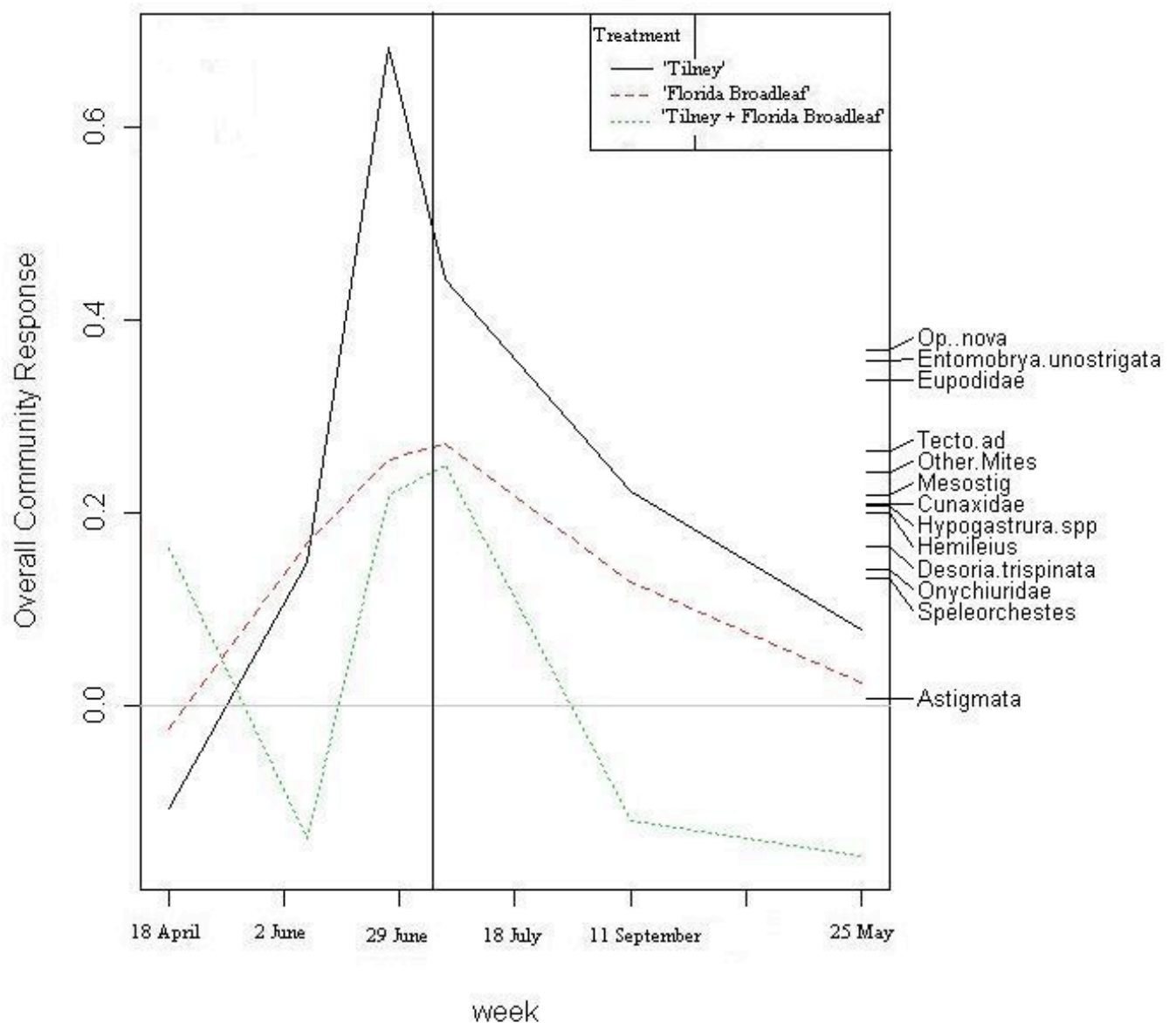


Table 1. Numbers of carabids collected in pitfall traps in plots where the mustard varieties Tilney, Florida Broadleaf (FBL), and Tilney + Florida Broadleaf were planted and in plots where no cover crop was grown, 2008.

Carabid species	Tilney	Florida Broadleaf	Tilney+FBL	No cover crop
<i>Anisodactylus santaecrucis</i> Fabricius	96	36	91	61
<i>Cicindela punctata</i> Olivier	1	0	0	0
<i>Clivinia impressifrons</i> LeConte	0	1	0	0
<i>Crutacanthus dubius</i> Paliset	1	0	0	1
<i>Cyclotachelus seximpressus</i> LeConte	0	5	2	0
<i>Harpalus pennsylvanicus</i> DeGeer	1	3	2	8
<i>Harpalus</i> spp	9	7	7	8
<i>Poecilus chalcites</i> Say	49	57	48	13
<i>Stenolophus</i> spp.	5	5	6	5
Total	162	114	156	96

Table 2. Means (and standard deviations) of overall carabid abundance (beetles per trap per day) in plots where the mustard varieties Tilney, Florida Broadleaf, and Tilney+Florida Broadleaf were planted and in plots where no cover crop was planted. Means among treatments did not differ significantly ($P=0.05$) on any sampling date.

Sampling period	Tilney	Florida Broadleaf	Tilney+FBL	No cover crop	<i>F</i> -value	<i>P</i> ($>F$)
6–9 April 2008	1.86 (1.37)	0.89 (1.26)	0.92 (0.72)	1.13 (0.86)	2.03	0.21
10–12 June 2008	1.41 (1.16)	2.12 (0.54)	2.25 (1.54)	0.79 (0.07)	2.14	0.20
24–27 June 2008	0.27 (0.27)	0.33 (0.30)	0.25 (0.08)	0.28 (0.34)	0.47	0.71
17–19 July 2008	1.84 (1.33)	2.88 (2.09)	2.63 (2.58)	1.58 (0.26)	0.57	0.65

Table 3. Means (and standard deviations) of dominant carabids ((beetles per trap per day)) collected in pitfall traps in plots where the mustard varieties Tilney, Florida Broadleaf, and Tilney+Florida Broadleaf were planted and in plots where no cover crop was planted. Means among treatments did not differ significantly ($P=0.05$) on any sampling date except 17-19 July for *P. chalcites*. For the 17-19 July sample, means followed by the same letter are not significantly different ($P=0.05$).

Sampling period	Tilney	Florida Broadleaf	Tilney + FBL	No cover crop	F-value	$P>F$
<i>Anisodactylus santaecrucis</i>						
6–9 April 2008	0.87 (0.56)	0.28 (0.48)	0.50 (0.31)	0.88 (0.78)	0.87	0.50
10–12 June 2008	1.03 (0.89)	1.21 (0.31)	1.50 (1.27)	0.63 (0.22)	0.71	0.58
24–27 June 2008	0.10 (0.04)	0.06 (0.05)	0.03 (0.05)	0.11 (0.05)	1.81	0.24
17–19 July 2008	1.09 (0.94)	1.38 (1.35)	1.58 (1.77)	0.71 (0.26)	0.40	0.76
<i>Poecilus chalcites</i>						
6–9 April 2008	0.92 (0.83)	0.61 (0.79)	0.31 (0.25)	0.14 (0.07)	2.31	0.18
10–12 June 2008	0.34 (0.26)	0.83 (0.72)	0.71 (0.32)	0.17 (0.19)	2.03	0.21
24–27 June 2008	0.02 (0.04)	0.17 (0.17)	0.14 (0.09)	0.00 (0.00)	2.54	0.15
17–19 July 2008	0.13 (0.25)	0.88 (0.70)	0.67 (0.62)	0.21 (0.36)	5.39	0.04*

Table 4. Means of diversity indices for Carabidae collected in pitfall traps in plots where the mustard varieties Tilney, Florida Broadleaf (FBL), and Tilney+ Florida Broadleaf were planted and in plots where no cover crop was grown. Means among treatments did not differ significantly ($P=0.05$) on any sampling date.

Shannon (H')	Tilney	Florida Broadleaf	Tilney+FBL	No Cover Crop	F-value	$P>F$
6–9 April 2008	0.82	0.22	0.74	0.65	2.09	0.20
10–12 June 2008	0.41	0.57	1.9	0.37	0.32	0.81
24–27 June 2008	0.46	0.46	0.78	0.19	1.48	0.31
17–19 July 2008	0.59	0.59	0.73	1.09	1.61	0.28
Simpson (D)						
6–9 April 2008	0.53	0.49	0.46	0.38	0.18	0.91
10–12 June 2008	0.26	0.36	0.36	0.25	0.30	0.82
24–27 June 2008	0.33	0.63	0.63	0.13	1.88	0.23
17–19 July 2008	0.33	0.65	0.65	0.60	1.54	0.30
Species Richness (S)						
6–9 April 2008	2.7	1.0	2.3	2.7	4.00	0.07
10–12 June 2008	2.0	2.3	2.3	1.7	0.38	0.77
24–27 June 2008	1.7	1.7	2.3	1.3	0.68	0.60
17–19 July 2008	3.0	4.7	3.7	3.7	1.00	0.45

Table 5. Abundance of collembolans from soil cores taken from plots where the mustard varieties Tilney, Florida Broadleaf (FBL), and Tilney + Florida Broadleaf were planted and plots where no cover crops were grown.

Collembola species	Tilney	Florida Broadleaf	Tilney+FBL	No cover crop
Entomobryidae				
<i>Entomobrya unostrigata</i> Stach	247	102	364	86
<i>Lepidocyrtus cinereus</i> Folsom	3	15	6	3
<i>Pseudosinella</i> sp. 1	92	54	89	17
Hypogastruridae				
<i>Hypogastrura</i> spp.	729	535	772	770
Isotomidae				
<i>Desoria trispinata</i> (MacGillivray)	8,309	7,369	6,318	4,382
<i>Folsomia diplophthalma</i> Axelson	94	102	116	49
<i>Isotoma</i> sp. 1	12	24	36	8
<i>Isotomurus</i> sp. 1	90	28	54	60
Onychiuridae				
<i>Onychiuridae</i> sp.1	198	234	374	180
Sminthuridae				
<i>Sminthuris</i> sp. 1	23	28	35	26
<i>Sminthuris</i> sp. 2	0	2	1	0
Total	9,797	8,493	8,165	5,581

Table 6. Means (and standard deviations) of overall collembolan abundance (number per 4 soil cores per plot) in plots where the mustard varieties Tilney, Florida Broadleaf, and Tilney + Florida Broadleaf were planted and in plots where no cover crops were grown. Mustards were seeded on 21 May, and all plots were tilled on 2 July and 28 July. Means among treatments did not differ significantly ($P=0.05$) on any sampling date.

Sampling period	Tilney	Florida Broadleaf	Tilney+FBL	No cover crop	<i>F</i> -value	<i>P</i> > <i>F</i>
18 April 2008	70.2 (82.3)	46.9 (65.6)	88.7 (120.1)	86.9 (146.8)	0.45	0.72
2 June 2008	210.5 (357.6)	114.5 (127.0)	107.8 (222.3)	108.3 (113.4)	0.69	0.56
29 June 2008	90.8 (182.7)	15.3 (22.8)	27.4 (47.6)	12.6 (13.1)	2.17	0.11
18 July 2008	366.2 (233.4)	474.4 (412.1)	362.2 (266.0)	212.3 (204.1)	1.88	0.15
11 September 2008	49.5 (32.2)	46.8 (58.0)	59.9 (58.0)	31.6 (27.6)	0.63	0.60
25 May 2009	10.8 (5.1)	10.1 (14.6)	34.5 (55.9)	10.8 (13.2)	2.47	0.07

Table 7. Mean counts of common collembolans (number per 4 soil cores per plot) in plots where mustard cover crops were planted and plots where no cover crops were grown. Mustards were seeded on 21 May, and all plots were tilled on 2 July and 28 July. Means among treatments did not differ significantly ($P=0.05$) on any sampling date.

Sampling period	Tilney	Florida Broadleaf	Tilney + FBL	No cover crop	F – value	$P > F$
<i>Desoria trispinata</i>						
18 April 2008	16.7 (19.8)	23.3 (47.2)	34.8 (60.3)	43.3 (82.9)	0.76	0.52
2 June 2008	178.4 (321.6)	76.3 (96.3)	79.1 (179.3)	11.3 (97.0)	0.84	0.48
29 June 2008	75.3 (168.0)	11.3 (18.5)	17.4 (30.6)	11.3 (13.1)	1.47	0.24
18 July 2008	353.5 (229.4)	461.2 (409.6)	331.3 (255.4)	202.1 (201.7)	2.08	0.12
11 September 2008	33.2 (24.6)	34.8 (42.0)	34.6 (54.4)	22.2 (16.9)	0.17	0.91
25 May 2009	2.5 (4.6)	7.2 (13.0)	29.3 (53.7)	4.6 (4.8)	0.89	0.45
<i>Hypogastrura</i> spp.						
18 April 2008	42.6 (57.2)	15.7 (19.4)	47.0 (97.0)	41.8 (63.2)	0.32	0.81
2 June 2008	21.8 (15.2)	28.4 (47.1)	16.3 (33.3)	20.7 (41.6)	0.62	0.60
29 June 2008	0.8 (2.3)	0.3 (0.6)	0.3 (0.8)	0.0 (0.0)	0.82	0.49
18 July 2008	2.4 (7.2)	0.3 (0.5)	0.4 (1.2)	1.3 (3.7)	1.10	0.36
11 September 2008	0.2 (0.4)	0.0 (0.0)	0.3 (0.6)	0.3 (0.6)	1.01	0.40
25 May 2009	0.0 (0.0)	0.2 (0.4)	0.1 (0.3)	0.2 (0.6)	1.34	0.27
<i>Entomobrya unostrigata</i>						
18 April 2008	8.4 (29.0)	1.4 (1.6)	1.3 (1.3)	2.1 (2.5)	1.32	0.28
2 June 2008	3.0 (3.7)	3.6 (3.2)	3.6 (6.4)	2.5 (4.2)	0.45	0.72
29 June 2008	4.0 (4.3)	0.8 (0.72)	1.2 (1.7)	0.6 (0.8)	1.27	0.30
18 July 2008	3.8 (5.0)	2.4 (2.8)	21.3 (39.5)	1.7 (4.1)	2.42	0.08
11 September 2008	0.2 (0.0)	0.3 (0.5)	3.1 (7.5)	0.3 (0.7)	1.69	0.18
25 May 2009	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	N/A	N/A

Table 8. Means of diversity indices for collembolans by date in plots where the mustard varieties Tilney, Florida Broadleaf, and Tilney+Florida Broadleaf were planted and in plots where no cover crops were grown. Mustards were seeded on 21 May, and all plots were tilled on 2 July and 28 July. Within a row (sample date), means followed by the same letter are not significantly different ($P=0.05$).

Sampling date	Tilney	Florida Broadleaf	Tilney + FBL	No cover crop	<i>F</i> – value	<i>P</i> > <i>F</i>
Shannon (H')						
18 April 2008	0.47 b	0.96 a	0.83 a	0.95 a	5.97	0.002 *
2 June 2008	0.67 a	0.82 a	0.68 a	0.60 a	0.77	0.52
29 June 2008	0.72 a	0.72 a	0.63 a	0.30 a	2.50	0.07
18 July 2008	0.22 a b	0.21 b	0.40 a	0.30 a b	3.17	0.03 *
11 September 2008	0.71 a	0.74 a	0.76 a	0.82 a	0.55	0.65
25 May 2009	0.49 a b	0.22 a	0.70 b	0.52 a b	3.21	0.03 *
Simpson (D)						
18 April 2008	0.27 b	0.55 a	0.44 a	0.55 a	7.81	0.0003 *
2 June 2008	0.34 a	0.42 a	0.53 a	0.31 a	2.56	0.07
29 June 2008	0.38 a	0.41 a	0.44 a	0.17 a	2.63	0.06
18 July 2008	0.10 a b	0.08 b	0.19 a	0.14 a b	3.22	0.03 *
11 September 2008	0.41 a	0.44 a	0.43 a	0.47 a	0.40	0.75
25 May 2009	0.47 a	0.49 a	0.39 a	0.55 a	0.52	0.67
Species richness (S)						
18 April 2008	2.8 a	3.6 a b	4.3 b	3.6 a b	2.95	0.04 *
2 June 2008	4.5 a	5.3 a	3.7 a	4.2 a	1.34	0.27
29 June 2008	3.6 a	3.0 a	2.8 a	1.9 a	2.79	0.052
18 July 2008	4.1 b	4.3 b	4.3 b	3.2 a	4.26	0.01 *
11 September 2008	3.7 a	3.3 a	3.9 a	3.8 a	0.89	0.43
25 May 2009	1.2 a	2.5 a	2.7 a	2.0 a	2.66	0.06

Table 9. List of soil Acari.

Mesostigmata	Scheloribatidae	Prostigmata
Laelapidae	<i>Hemileius</i> sp. 1	Cunaxidae
<i>Laelaps</i> sp. 1	Tectocepheidae	<i>Pseudobonzia</i> sp. 1
Digamasellidae	<i>Tectocepheus velatus</i> (Michael)	Bdellidae
<i>Dendrolaelaps</i> sp. 1	<i>Tectocepheus minor</i> Berlese	<i>Neomolgus</i> sp. 1
<i>Digamasellus</i> sp. 1	Eupthiracaridae	Microtrombidiidae
Rhodacaridae	<i>Acrotritia</i> sp. 1	<i>Microtrombium</i> sp. 1
<i>Rhodacarus</i> sp. 1	Oppiidae	Eupodidae
	<i>Oppiella nova</i> Oudemans	<i>Eupodes</i> sp. 1
Endeostigmata	<i>Oppiella</i> sp. 2	<i>Claveupodes</i> sp. 1
Nanorchestidae	<i>Microppia</i> sp. 1	<i>Protereunetes</i> sp. 1
<i>Nanorchestes</i> spp.	Brachythoniidae	Rhagidiidae
<i>Speleorchestes</i> spp.	<i>Eobrachythonius</i> sp. 1	Rhagidiid sp. 1
	Enarthronota sp. 1	Pygmephoridae
Oribatida	Galumnidae sp. 1	<i>Pygmephorus</i> sp. 1
Ceratozetidae		Tarsonemidae
<i>Ceratozetes</i> sp. 1	Astigmata	<i>Tarsonemus</i> sp. 1
<i>Protozetomimus</i> nr. sp. 1	Glycyphagidae	Scutacaridae
	<i>Cosmoglyphus</i> sp. 1	<i>Scutacarus</i> sp. 1

Table 10. Abundance of Acari by treatment from soil cores taken from plots where the mustard varieties Tilney, Florida Broadleaf (FBL), and Tilney + Florida Broadleaf were planted and in bare-ground plots, 2008 and 2009.

	Tilney	Florida Broadleaf	Tilney + FBL	No cover crop
Acari species				
Astigmata spp.	951	424	316	502
Endeostigmata				
<i>Speleorchestes</i> spp.	387	292	310	233
Mesostigmata spp.	276	368	293	160
Oribatida				
<i>Acrotritia</i> sp. 1	6	5	7	2
<i>Ceratozetes</i> sp. 1	20	16	39	16
<i>Enarthronota</i> sp. 1	293	352	301	226
<i>Galumnidae</i> sp. 1	1	0	0	0
<i>Hemileius</i> sp. 1	367	451	391	302
<i>Macropylina</i> sp. 1	7	4	4	10
<i>Macropylina</i> sp. 2	7	0	0	2
<i>Microppia</i> sp. 1	25	14	19	10
<i>Oppiella nova</i> Oudemans	394	304	342	333
Poronotic Brachypylina sp. 4	1	2	0	2
Poronotic Brachypylina sp. 5	23	5	14	7
Poronotic Brachypylina sp. 6	38	42	47	18
<i>Protozetomimus</i> sp. 1	3	15	28	8
<i>Tectocephus</i> spp. (Adults)	125	215	153	98
<i>Tectocephus</i> spp. (Nymphs)	47	87	82	10
Prostigmata				
Cunaxidae spp.	323	175	232	101
Eupodoidea spp.	201	235	249	131

Table 10 continued.

<i>Neomolgus</i> sp. 1	0	2	0	0
Rhagidiidae spp.	7	5	0	4
<i>Scutacarus</i> sp. 1	8	12	17	10
<i>Tarsonemus</i> spp.	51	16	54	13
Total	3,138	3,041	2,898	2,198

Table 11. Means (and standard deviations) of overall mite density (per m²) collected from soil cores in plots where the mustard varieties Tilney, Florida Broadleaf, Tilney+Florida Broadleaf were planted and in plots where no cover crops were grown. Mustards were seeded on 21 May, and all plots were tilled on 2 July and 28 July. Means among treatments did not differ significantly ($P=0.05$) on any sampling date.

Sampling period	Tilney	Florida Broadleaf	Tilney+FBL	No cover crop	<i>F</i> -value	<i>P</i> > <i>F</i>
18 April 2008	6848.5 (7482.8)	4265.5 (7482.8)	8060.6 (10917.3)	8143.9 (13343.2)	0.45	0.72
2 June 2008	19333.3 (32510.1)	10409.1 (11545.7)	9803.0 (20212.1)	9840.9 (10305.7)	0.69	0.57
29 June 2008	8742.4 (16609.4)	1386.4 (2074.2)	2492.4 (4326.2)	1143.9 (1191.3)	2.17	0.11
18 July 2008	34848.5 (21222.5)	43128.8 (37460.6)	32924.2 (24181.1)	19303.0 (18557.4)	1.88	0.15
11 September 2008	4143.9 (2924.7)	4257.6 (5271.7)	5447.0 (7459.0)	2871.2 (2506.6)	0.63	0.60
25 May 2009	333.3 (464.1)	916.7 (1331.3)	3136.4 (5083.2)	984.8 (1200.9)	2.47	0.07

Table 12. Mean counts of selected mite taxa (number per 4 soil cores per plot) in plots where mustard cover crops were planted and plots where no cover crops were grown. Mustards were seeded on 21 May, and all plots were tilled on 2 July and 28 July. Means among treatments did not differ significantly ($P=0.05$) on any sampling date except 18 July for cunaxids. For the 18 July sampling date, means (of cunaxids) followed by the same letter are not significantly different ($P=0.05$).

Sampling date	Tilney	Florida Broadleaf	Tilney + FBL	No cover crop	<i>F</i> – value	<i>P</i> > <i>F</i>
<i>Hemileius</i> sp. 1						
18 April 2008	1.3 (2.6)	3.8 (4.4)	4.1 (4.0)	6.2 (10.9)	1.32	0.28
2 June 2008	4.0 (12.2)	2.9 (3.2)	4.4 (9.7)	2.7 (3.7)	0.64	0.60
29 June 2008	4.8 (4.8)	3.8 (3.4)	2.7 (2.1)	3.1 (4.2)	0.42	0.74
18 July 2008	9.4 (7.6)	14.4 (18.5)	12.0 (17.3)	5.3 (3.2)	1.57	0.21
11 September 2008	8.5 (5.1)	10.4 (10.4)	6.9 (7.9)	6.1 (6.1)	0.44	0.72
25 May 2009	2.0 (1.7)	2.3 (2.5)	2.5 (3.5)	2.0 (1.3)	0.86	0.47
<i>Oppiella nova</i>						
18 April 2008	4.3 (7.6)	4.6 (4.2)	8.3 (7.0)	12.4 (16.1)	1.43	0.25
2 June 2008	1.9 (2.5)	1.4 (7.2)	6.1 (4.0)	1.4 (2.0)	1.46	0.24
29 June 2008	3.5 (4.1)	2.2 (2.6)	2.4 (3.0)	0.9 (1.6)	1.30	0.29
18 July 2008	9.2 (12.5)	4.6 (5.1)	6.0 (6.8)	4.1 (5.1)	0.76	0.52
11 September 2008	9.0 (7.5)	7.1 (6.3)	5.8 (6.9)	6.4 (5.6)	2.51	0.07
25 May 2009	3.6 (2.9)	0.8 (1.4)	3.0 (3.6)	2.5 (2.0)	1.51	0.23
<i>Tectocephus</i> spp.						
18 April 2008	1.3 (2.3)	1.5 (3.4)	1.8 (1.9)	1.3 (2.0)	0.54	0.66
2 June 2008	1.5 (2.2)	4.5 (6.8)	2.3 (4.0)	1.5 (2.9)	1.04	0.38
29 June 2008	2.6 (4.4)	2.8 (3.6)	2.0 (3.8)	0.7 (0.89)	2.24	0.10
18 July 2008	4.2 (7.2)	5.5 (6.7)	4.5 (4.7)	3.0 (4.5)	0.20	0.90
11 September 2008	1.2 (1.5)	3.1 (4.1)	1.5 (2.2)	1.3 (1.6)	1.82	0.16
25 May 2009	0.3 (0.6)	0.5 (0.8)	0.7 (1.2)	0.3 (0.7)	1.65	0.19

Table 12
continued

<i>Speleorchestes</i> spp.						
18 April 2008	2.5 (5.2)	5.8 (7.1)	3.3 (3.7)	2.3 (3.4)	0.62	0.60
2 June 2008	7.3 (12.3)	3.4 (7.5)	1.1 (1.8)	4.0 (7.0)	1.16	0.34
29 June 2008	18.1 (15.4)	11.3 (7.9)	14.0 (12.1)	8.8 (7.2)	2.36	0.09
18 July 2008	2.4 (4.0)	4.8 (6.4)	3.5 (6.0)	3.3 (4.0)	0.63	0.60
11 September 2008	1.1 (1.8)	0.6 (1.2)	0.6 (1.9)	0.8 (1.0)	1.07	0.37
25 May 2009	0.3 (0.6)	0.2 (0.4)	0.1 (0.3)	0.3 (0.5)	0.10	0.96
<i>Mesostigmata</i> spp.						
18 April 2008	0.0 (0.0)	0.1 (0.3)	2.3 (5.3)	0.5 (0.7)	0.77	0.52
2 June 2008	1.8 (3.2)	2.1 (5.5)	2.9 (7.9)	2.9 (5.2)	0.78	0.51
29 June 2008	1.2 (1.8)	0.6 (0.7)	0.7 (1.2)	0.3 (0.7)	1.52	0.49
18 July 2008	13.0 (13.6)	5.3 (18.1)	16.6 (23.2)	11.0 (7.5)	1.52	0.22
11 September 2008	5.8 (4.9)	10.9 (18.5)	7.3 (12.9)	4.2 (4.7)	1.12	0.35
25 May 2009	0.6 (1.4)	0.4 (0.8)	0.3 (0.9)	0.2 (0.4)	0.53	0.67
<i>Cunaxidae</i> spp.						
18 April 2008	0.2 (0.4)	0.3 (0.9)	0.4 (1.0)	0.1 (0.3)	0.78	0.51
2 June 2008	0.3 (0.5)	0.0 (0.0)	0.1 (0.3)	0.3 (0.5)	0.43	0.73
29 June 2008	4.9 (4.5)	3.6 (3.7)	3.8 (3.1)	2.0 (2.4)	2.97	0.95
18 July 2008	17.2 (28.0) b	8.3 (9.3) a b	13.4 (21.8) a b	4.1 (5.7) a	2.97	0.04 *
11 September 2008	3.0 (2.6) a	2.3 (1.3) a	1.7 (1.3) a	1.8 (1.6) a	1.29	0.29
25 May 2009	0.1 (0.3) a	0.0 (0.0) a	0.0 (0.0) a	0.1 (0.3) a	0.65	0.59

Table 13. Means of diversity indices for mites by date in plots where the mustard varieties Tilney, Florida Broadleaf, and Tilney+Florida Broadleaf were planted and in plots where no cover crops were grown. Mustards were seeded on 21 May, and all plots were tilled on 2 July and 28 July. Within a row (sample date), means followed by the same letter are not significantly different ($P=0.05$).

Sampling date	Tilney	Florida Broadleaf	Tilney + FBL	No cover crop	<i>F</i> – value	<i>P</i> > <i>F</i>
Shannon (H')						
18 April 2008	1.32 a	1.40 a b	1.74 b	1.39 a b	6.17	0.001 *
2 June 2008	1.22 a	1.47 a	1.53 a	1.25 a	0.22	0.88
29 June 2008	1.71 b	1.64 a b	1.51 a b	1.32 a	4.43	0.009 *
18 July 2008	1.65 a	1.68 a	1.61 a	1.66 a	0.22	0.88
11 September 2008	1.50 a	1.44 a	1.46 a	1.42 a	0.64	0.59
25 May 2009	1.05 a	1.07 a	1.18 a	1.18 a	0.09	0.97
Simpson (D)						
18 April 2008	0.74 a	0.68 a	0.75 a	0.68 a	2.02	0.13
2 June 2008	0.59 a	0.65 a	0.74 a	0.58 a	2.72	0.06
29 June 2008	0.77 a	0.74 a	0.70 a	0.63 a	1.51	0.23
18 July 2008	0.73 a	0.72 a	0.77 a	0.82 a	0.28	0.84
11 September 2008	0.75 a	0.69 a	0.65 a	0.74 a	1.71	0.18
25 May 2009	0.54 a	0.58 a	0.66 a	0.59 a	1.14	0.34
Species richness (S)						
18 April 2008	5.9 a b	5.8 a	8.4 b	6.5 a b	2.96	0.04 *
2 June 2008	6.7 a	6.1 a	6.1 a	6.1 a	0.01	1.00
29 June 2008	8.8 b	7.8 a b	7.6 a b	6.2 a	4.39	0.009 *
18 July 2008	8.7 a	9.0 a	8.0 a	7.6 a	0.94	0.43
11 September 2008	6.5 a	6.3 a	5.8 a	5.8 a	1.37	0.27
25 May 2009	4.3 a	3.8 a	4.4 a	4.7 a	0.66	0.58

Appendix Table 1 Mean dry weight (g/m²) plant biomass per treatment plot on 24 June 2008, one week before incorporation.

	Tilney	Florida Broadleaf	Tilney+FBL	No cover crop
Mustard biomass (g)	12.7	18.2	11.6	0.0
Total plant biomass (g)	19.6	21.4	16.0	21.2

Appendix Table 2. Average daily temperatures (Celsius) and total precipitation (cm) for April through September 2008, and May, 2009, and for specific dates when pitfall traps were in place. (Values from the Midwestern Regional Climate Center, University of Illinois Willard Airport, IL 2010).

Sampling Period	Sampling Method	Average Daily Temperature (C°)	Total Precipitation (cm)
April 2008		15.9	13.1
May 2008		21.4	11.1
June 2008		28.6	21.1
July 2008		29.6	18.4
August 2008		28.5	4.1
September 2008		24.4	20.6
May 2009		23.2	11.6
6–9 April 2008	Pitfall traps	11.4	0.4
10–12 June 2008	Pitfall traps	22.6	0.4
24–27 June 2008	Pitfall traps	24.1	0.1
17–19 July 2008	Pitfall traps	25.3	0.3

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