Influence of winter annual cover crops and insect management strategies on insect pests of Mississippi soybean

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An increasing cultural practice in soybean, *Glycine max* (L.), production is the use of winter annual cover crops before planting. Species of grasses, legumes, and forbs are planted for many agronomic purposes during the fall months. In the spring, cover crops are killed and soybean planted into the residue. When the termination of the cover crops is delayed for longer lasting benefits, insect pest issues can arise. The movement of insect pests from cover crops to subsequent cash crops happens through a connection known as the "Green Bridge". Pests found in cover crops such as the pea leaf weevil, *Sitona lineatus* L. (Coleoptera: Curculionidae), can be particularly damaging to immature soybean plants. Experiments were conducted to tests how cover crops influence insect populations in soybean. Also, various chemical control options, soybean planting populations, and the timing of cover crop termination prior to planting were tested in these cover crop-soybean systems. Lastly, an experiment was conducted to measure how various species of cover crops and neonicotinoid seed treatments affect arthropod diversity in soybean fields.

DEDICATION

I would like to dedicate this dissertation to my loving fiancée, Sara, and my parents, Danny and Tammy. Your love and support throughout this process has been instrumental to my success.

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Cover Crops

Definition and Techniques

Cover crops are unharvested cultivations of plants that are implemented into agricultural fields for seasonal cover and other conservation purposes (USDA-NRCS 2014). They are often implemented in association with conservation tillage or no-tillage programs (Wiggins et al. 2016, Montgomery et al. 2018). The planting of cover crop seed can extend from late summer through the fall months. In some situations, cover crop seeds are broadcasted within a standing cash crop before the cash crop is harvested (Hively and Cox 2001). This gives the cover crop more time to grow and maximize the production of biomass. Cover crop seed is typically broadcasted by a ground spreader or airplane, or drilled into the soil.

Cover crop plantings that are not killed by cold weather during the winter must be terminated through the use of chemical or mechanical action. Glyphosate and 2,4-D or dicamba are commonly used herbicides for terminating cover crops (Montgomery et al. 2018). Mowers and roller-crimpers can be used to mechanically terminate and manage previously sprayed cover crops (Davis 2010). Termination timing is usually based on the desired purpose of the cover crop. Some producers terminate cover crops near or at planting when trying to achieve the greatest cover crop biomass for suppression of early season weeds (Mirsky et al. 2013, Montgomery et al. 2018). Other groups recommend terminating a cover crop three to four weeks prior to planting to avoid pest issues (Lorenz and Goodson 2014).

Reeves (1994) provided a list of requirements for potential cover crops. The potential cover crop must be easily established and have a rapid growth rate to cover the ground quickly. It should produce a sufficient amount of dry matter to maintain residues. The cover crop should not act as a disease host for the subsequent cash crop. It should be easily killed, and it should be economically viable. For a cover crop to meet these specifications, factors such as soil parameters, climate, the succeeding cash crop, and characteristics of the cover crop must be considered (Reeves 1994).

Cover crop plantings can be grasses, legumes, or forbs and consist of a monoculture or multiple species blends (USDA-NRCS 2014). Clark (2008) lists eight cover crop species as the top species to use in the Mid-South agricultural region (Table 1.1). Other popular species in the region include winter wheat, *Triticum aestivum* L. (Poales: Poaceae), triticale, *S. cereale* L. *x Triticum aestivum* L. (Poales: Poaceae), tillage radish, *Raphanus sativus* (L.) var. *niger* (Brassicales: Brassicaceae), and Austrian winter pea, *Pisum sativum* L. subsp. *arvense* (Fabales: Fabaceae). Producers choose different species and blends depending on the desired agronomic benefit each may provide.

Cover Crop Benefits

Soil Erosion

Soil erosion is the detachment and movement of soil particles from one area to another through the means of rainfall, irrigation runoff, or wind (USDA-NRCS 2012). Soil erosion can lead to reductions of soil quality and structure (USDA-NRCS 2012). When water runoff in a field moves soil particles, soil channels or rills can form and eventually can form gullies and ravines (USDA-NRCS 2012). Soil erosion naturally occurs, but soil formation is a slow process that does not benefit from intensive agricultural practices (USDA-NRCS 2012).

Soil erosion can have major impacts outside of a production field. One major off-site effect is increased sediment in waterways (Clark 1985). This sediment disrupts aquatic ecosystems and can contaminate drinking water (Clark 1985). Sedimentation is the most limiting pollutant to fishery health in the Mississippi Delta (Yuan et al. 2002). Prevention of soil erosion not only benefits agricultural producers but also the general public.

Cover crops aid in combatting soil erosion by grasping soil particles and preventing their movement out of fields with exiting water and wind (Clark 2008, USDA-NRCS 2012,). During periods of time where crops are not occupying the field, winter cover crops can protect soil particles from heavy rainfall and reduce soil runoff (Clark 2008). Clark (2008) attributes erosion control to six of the common Mid-South cover crops: hairy vetch, *Vicia villosa* Roth, crimson clover, *Trifolium incarnatum* L., winter wheat, triticale, annual ryegrass, *Lolium multiflorum* Lam., and cereal rye, *Secale cereale* L.. Zhu et al. (1989) showed an increase in soil cover of 30 to 50% when using different cover crops to combat erosion in Missouri soybean. The use of common chickweed, *Stellaria media* L. (Caryophyllales: Caryophyllaceae), Canada bluegrass, *Poa compressa* L. (Poales: Poaceae), and downy brome, *Bromus tectorum* L. (Poales: Poaceae) decreased mean annual soil losses by 87, 96 and 95% and reduced runoff by 44, 45 and 53%, respectively, when compared to soybean planted behind no cover (Zhu et al. 1989).

Soil Compaction

Soil compaction is the movement of soil particles closer together when forcibly pressed causing reductions in the air space between particles (Franzmeier et al. 2009, USDA-NRCS 2012). In row crop agricultural fields, this can occur through external forces such as heavy rain periods and the weight of heavy farm equipment (Franzmeier et al. 2009, USDA-NRCS 2012). Soil compaction can result in reductions of seed emergence, grain yield, soil water storage, and crop-water use efficiency (Radford et al. 2001). Deep rooted cover crops planted in the winter can provide root channels and create low resistance paths for the roots of later planted cash crops to follow and reach the subsoil layer in compacted fields (Williams and Weil 2004). Five of the top Mid-South cover crop species can help with compaction and soil moisture problems: hairy vetch, subterranean clover, *Trifolium subterraneum* L., sweetclover, *Melilotus officinalis* (L.), tillage radish, and sorghum-sudangrass hybrid, *Sorghum bicolor* (L.) *x S. bicolor* (L.) *var. sudanese* (Clark 2008).

Soil Fertility

Legume plants naturally fix atmospheric nitrogen (N2) in nodules on their roots (Lindemann and Glover 2003). A symbiotic relationship with the bacteria, *Rhizobium*, allows these plants to convert N2 into NH3 that can be readily absorbed into the plant (Lindemann and Glover 2003). The decomposing plant residues, roots, and nodules from previously planted winter annual legume cover crops can provide later planted cash crops with around two-thirds of the nitrogen fixed by the cover crop that was growing (USDA-NRCS 1998). Non-legume cover crops can also contribute to providing nitrogen to later planted cash crops. Grass and *Brassica* cover crops have to ability to scavenge the soil for residual nitrogen that originated from fertilizer applications or mineralized organic matter

(Clark 2008, Kladivko and Fisher 2011). Popular Mid-South cover crops that fix nitrogen or scavenge nutrients include hairy vetch, subterranean clover, berseem clover, *Trifolium alexandrinum* L., crimson clover, cowpea, *Vigna unguiculata* (L.), sweetclover, Austrian winter pea, buckwheat, *Fagopyrum esculentum* Moench, winter wheat, triticale, annual ryegrass, and cereal rye (Clark 2008).

Weed Control

Herbicide resistant weeds have become a major issue in the Mid-South region of the United States. Pressure from intense herbicide usage has led to herbicide resistance in multiple weed species (Norsworthy et al. 2012, Montgomery et al. 2018). One strategy for combatting early-season herbicide resistant weeds is implementing winter annual cover crops. Cover crops create unfavorable environmental conditions for early season weeds by decreasing light availability to the ground that inhibits the germination of weed seeds (Norsworthy et al. 2012). Delaying termination of these cover crops until near or right at planting of the cash crop can increase the longevity of weed control (Mirsky et al. 2013, Montgomery et al. 2018). Montgomery et al. (2018) reported a delay in the presence of 10 cm tall Palmer amaranth, *Amaranthus palmeri* S. Wats. (Caryophyllales: Amaranthaceae) when delaying cover crop termination.

Other early-season weed populations can be reduced when implementing cover crops before soybean planting. Reddy et al. (2003) was able to show reduced densities of barnyardgrass, *Echinochloa crus-galli* (L.) (Poales: Poaceae), broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) (Poales: Poaceae), browntop millet, *Brachiaria ramosa* (L.) (Poales: Poaceae), entireleaf morningglory, *Ipomoea hederacea* var. *integriuscula* Gray (Solanales: Convolvulaceae), and hyssop spurge, *Euphorbia hyssopifolia* L.

(Malpighiales: Euphorbiaceae) for seven weeks in soybean planted behind cover crops of crimson clover and cereal rye in the Mississippi Delta. The primary cover crops used for weed control in the Mid-South are cereal rye, winter wheat, triticale, sorghum-sudangrass hybrid, annual ryegrass, buckwheat, subterranean clover, and hairy vetch (Clark 2008).

Cover Crop Impacts on Insect Pests of Midsouth Soybean

The "Green Bridge"

When insect pests from a winter cover crop move into a spring cash crop, the connection from cover crop to cash crop is often referred to as the "Green Bridge" (Lorenz and Goodson 2014, Hodgson et al. 2015, White et al. 2015). A cover crop can host phytophagous insects in the field over the winter and early spring months. During this time, a variety of species of naturally occurring vegetation usually would occupy the field instead of abundant growths of one or a few species. A landscape dominated by only a few species of host plants can result in populations of insects feeding on those species to surge. Producers who terminate late to increase biomass for extended weed control and other agronomic benefits pose an increased risk of early season insect infestations. Below is a review of pest species occurring on cover crops that can carry over to Mississippi soybean, *Glycine max* (L.) (Fabales: Fabaceae).

Pea Leaf Weevil

The pea leaf weevil, *Sitona lineatus* L. (Coleoptera: Curculionidae), is a pest that can be found in early vegetative soybean following winter legume cover crops. Weevil adults are about 5 mm long and grayish-brown in color with three longitudinal stripes on the body behind the head (Price et al. 2009). Adults feed on the leaves of leguminous plants (Hoebeke and Wheeler 1985); whereas, the larvae chew into and feed upon the legume root nodules in the soil that contain the nitrogen-fixing bacteria, *Rhizobium leguminosarum* Frank (Rhizobiales: Rhizobiaceae) (Johnson and O'Keeffe 1981). Adult feeding typically resembles semi-circle notches around leaf edges that can progress to complete defoliation and main stem feeding (Price et al. 2009).

Before the winter months, weevil adults will move into secondary leguminous hosts where they will form shelter beds to overwinter (Schotzko and O'Keeffe 1988). These secondary leguminous hosts can include clovers, vetches, and winter pea cover crops. Adults will emerge during early spring and migrate to primary hosts, such as pea and bean crops, where they will feed on seedling plants (Fisher and O'Keeffe 1979; Landon et al. 1995). In a winter cover crop-soybean system, pea leaf weevil can be detrimental to a newly established soybean stand. When leguminous cover crops are terminated, pea leaf weevils in the field will move onto any recently emerged soybean seedlings (Lorenz and Goodson 2014). Larvae developing in the soil will continue to emerge from previously planted legume cover crops, and adults will proceed to feed on the vulnerable soybean seedlings (Lorenz and Goodson 2014). The adult beetles will completely defoliate the plants, which can lead to entire stand losses (Lorenz and Goodson 2014).

Pea leaf weevil can be easily controlled in soybean through the use of neonicotinoid seed treatments containing imidacloprid, thiamethoxam, or clothianidin (Price et al. 2009, Cook and Gore 2014, Lorenz and Goodson 2014, Cook et al. 2016). Foliar spray applications containing the highest labeled rates of pyrethroid insecticides can effectively control pea leaf weevil (Price et al. 2009), but fields must continuously be scouted when foliar sprays are the only control measure due to potential new migrations and the continued emergence of adult pea leaf weevil from developmental sites in the soil (Lorenz and Goodson 2014).

Three Cornered Alfalfa Hopper

The threecornered alfalfa hopper, *Spissistilus festinus* (Say) (Hemiptera: Membracidae), is a sap feeding insect that can be found on a wide variety of hosts plants, including soybean and many species used as cover crops such as cowpea, winter wheat, sweetclover, and vetch (Wildermuth 1915). Both adults and nymphs feed on the stem of the plant where they can make a single puncture or continuously puncture the plant forming a girdle (Wildermuth 1915). Girdling prevents nutrient flow through the phloem (Mitchell and Newsom 1984) that can lead to damage such as breakage, lodging, and plant death. The three cornered alfalfa hopper adult is approximately 6 mm in length, green in color, and triangularly shaped (Davis 1969). Nymphs are light-green to brownish in color with 12 pairs of spines running along the topside of the body (Davis 1969).

Three cornered alfalfa hopper will overwinter in leguminous species as well as other non-leguminous hosts (Newsom et al. 1983). It has also been noted that the three cornered alfalfa hopper can remain “active” on host plants in winter months in warm areas of the United States, such as the state of Louisiana (Wildermuth 1915). Winter annual cover crops can provide refuge of three cornered alfalfa hoppers that could lead to early season infestations in soybean fields.

Three cornered alfalfa hoppers should be treated in vegetative soybean when the soybean plant population is reduced below the desired stand (Catchot et al. 2018). In Mississippi soybean, three cornered alfalfa hopper are controlled with foliar applications of organophosphates and pyrethroids (Catchot et al. 2018). Neonicotinoid seed treatments containing imidacloprid and thiamethoxam can also provide good control for approximately 3 to 4 weeks after planting (Catchot et al. 2018).

Bean Leaf Beetle

The bean leaf beetle, *Ceratoma trifurcata* (Forster) (Coleoptera: Chrysomelidae) is a defoliating pest of soybean. Adult bean leaf beetles feed on the leaves and pods of leguminous plants, and the larvae feed on the roots and nodules (Funderburk et al. 1999). Adult feeding can be especially damaging on seedling soybean plants. Adults are approximately 6 mm in length with either light yellow or red elytra with a black margin on the outer edge and with or without four black spots (Hadi et al. 2012, Pedigo 1994). Larvae, which reside in the soil, are white with a black head (Hadi et al. 2012).

Bean leaf beetle overwinter as adults in leaf litter and grass near field edges, pastures, and forests (Funderburk et al. 1999, Pedigo 1994). Active observations of bean leaf beetles in winter months have been recorded in some southern regions of the United States (McConnel 1915). After winter conditions subside, adults of bean leaf beetles will migrate to leguminous hosts before eventually moving into soybean fields (Funderburk et al. 1999). Therefore, leguminous cover crops such as vetch, clovers, and winter peas provide a perfect window to introduce bean leaf beetles to vegetative soybean plants. During early vegetative growth stages, soybean defoliation can lead to total plant loss.

In Mississippi soybean fields, the threshold for bean leaf beetle defoliation is 35% during vegetative soybean growth stages (Catchot et al. 2018). Foliar sprays of labeled pyrethroids are recommended to control bean leaf beetle infestations (Catchot et al. 2018). A neonicotinoid seed treatment of imidacloprid or thiamethoxam can provide control of bean leaf beetles in soybean for around 3 to 4 weeks after planting (Catchot et al. 2018).

Lepidopteran Pests

Various lepidopteran pests can be influenced by the use of winter annual cover crops before soybean. Cutworm species that occasionally infest soybean in Mississippi include the black cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae), the granulate cutworm, *Agrotis subterranea* (F.) (Lepidoptera: Noctuidae), and the variegated cutworm, *Peridroma saucia* (Hubner) (Lepidoptera: Noctuidae). Planting hairy vetch and crimson clover cover crops fosters the development of cutworm infestations (Dabney et al. 2001, Leonard et al. 1994). Cutworms can clip soybean seedlings at the soil surface and hide under field debris (Catchot et al. 2018) such as cover crop residue. When plant populations are decreased beyond soybean stand recommendations, a pyrethroid can be used to control cutworm infestations (Catchot et al. 2018).

Winter cover crops such as the clovers and vetch can act as early season hosts for corn earworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), and tobacco budworm, *Chloridea virescens* (F.) (Lepidoptera: Noctuidae), (Stadelbacher 1981). When these noctuids infest legume cover crops, they will pupate in the soil and emerge in the later planted crop (Dabney et al. 2001). Depending on the growth stage and other nearby hosts, emerging moths could potentially lay eggs in the developing soybean field resulting in caterpillars that can defoliate leaves as well as feed on reproductive structures. Heliothines in soybean should be treated at 35% defoliation before bloom and at nine caterpillars per 25 sweeps in reproductive soybean (Catchot et al. 2018).

Epigeal Communities

The epigeal community is composed of species living at the ground level. Changing this habitat through residue management practices such as tillage and cover crops can greatly alter these communities. Members of the epigeal communities in soybean fields include important predators like beetles, spiders, and ants that can attack prey on the soil surface as well as on the plant (Kendall 2003). Conservation tillage systems can support larger and more diverse arthropod communities compared to conventional tillage soybean systems (House and Stinner 1983). A winter annual cover crop can provide habitat for arthropods during the time of year when cash crops are not present in the field and also in residue on the soil surface after the cover crop has been terminated. Cover crops such as cereal rye and red clover, *Trifolium pratense* L. (Fabales: Fabaceae), have been shown to increase the activity-density of carabid ground beetles in succeeding soybean fields (Dunbar et al. 2017, Carmona and Landis 1999).

Early Season Insect Control in Mississippi Soybean

Early Soybean Production System

There has been a recent switch in agronomic practices involving soybean cultivation in the Mid-South. The Early Soybean Production System has been widely adopted where early maturing, indeterminate soybean varieties are planted between the end of March through early April to avoid heat and drought stress later in the year during reproductive growth stages when stress can have critical impacts to yield potential (Heatherly 1999). In this new system, Maturity Group IV and early-Maturity Group V soybean varieties have replaced late-Maturity Group V and Maturity Group VI varieties (Heatherly 1999). Widespread adoption of the Early Soybean Production System has increased the importance of early season insect protection due to an abundance of suitable hosts for early season pests (Baur et al. 2000).

Early Season Pest Control Options

Early season pests in seedling soybean in the Mid-South can be difficult to monitor, making treatment decisions difficult (North et al. 2016). Some of these pests damage seedlings under the soil and are impossible to detect until plants are injured and stands reduced. In most cases, neonicotinoid seed treatments applied to the seed coat before planting are the only available option. The systemic nature of neonicotinoids allows for control of both above and belowground feeding pests (Maienfisch et al. 2001). In an analysis of 10 years of small plot research involving neonicotinoid seed treatment efficacy in Mid-South soybean, North et al. (2016) reported a 132.0 kg ha-1 difference in soybean yield when using a neonicotinoid and fungicide seed treatment compared to soybean seed only treated with fungicide.

Recently, neonicotinoid seed treatments have been scrutinized due to accusations of a connection between the insecticidal seed treatments and decreases in honey bee colony health. Areas around the world, including parts of Europe and Canada, have banned the use of neonicotinoid seed treatments with little concern for their benefits in IPM. It is important that the efficacy of neonicotinoid seed treatments and any other control options are explored for all labeled cropping systems including winter cover crop-soybean systems before truly understanding their economic influence in row crop production agriculture.

Justification for Further Research

The use of winter annual cover crops before soybean cultivation has been an increasing trend in Mississippi. Winter annual cover crops can provide many agronomic benefits, but not much is known about their influence on potential early season pest problems in Mississippi Soybean. To examine how these practices affect pest control in Mississippi soybean, the following objectives were proposed:

Objective 1: Determine the influence of winter annual cover crops on soybean insect pests and examine potential management strategies.

Objective 2: Determine how winter annual cover crop termination timing affects insect pressure and control in Mississippi soybean.

Objective 3: Determine how various winter annual cover crop species and insecticidal seed treatments affect terrestrial and foliar arthropod communities in Mississippi soybean.

Table 1.1 Top cover crop species in the Mid-South agricultural region (Clark 2008).

Common Name	**Scientific Name**	**Order**	**Family**
Hairy Vetch	*Vicia villosa* Roth	Fabales	Fabaceae
Subterranean Clover	*Trifolium subterraneum* L.	Fabales	Fabaceae
Berseem Clover	*Trifolium alexandrinum* L.	Fabales	Fabaceae
Crimson Clover	*Trifolium incarnatum* L.	Fabales	Fabaceae
Annual Ryegrass	*Lolium multiflorum* Lam.	Poales	Poaceae
Cereal Rye	*Secale cereale* L.	Poales	Poaceae
Sorghum-Sudangrass Hybrid	*Sorghum bicolor* (L.) Moench *x S. bicolor* (L.) Moench *var. sudanese*	Poales	Poaceae
Cowpea	*Vigna unguiculata* (L.) Walp.	Fabales	Fabaceae
Sweetclover	*Melilotus officinalis* (L.) Lam.	Fabales	Fabaceae
Buckwheat	*Fagopyrum esculentum* Moench	Caryophyllales	Polygonaceae

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CHAPTER II

INFLUENCE OF WINTER ANNUAL COVER CROPS AND EARLY SEASON INSECT CONTROL STRATIGIES ON EARLY SEASON INSECT PESTS OF SOYBEAN

Introduction

Winter annual cover crops are implemented into soybean cropping systems to improve soil quality and to suppress early season weeds (USDA-NRCS 2014, Clark 2008). These monocultures and mixes of grasses, legumes, and forbs are planted in the fall months and allowed to grow throughout the winter and early spring (USDA-NRCS 2014). Clark (2008) lists eight cover crop species as the top species to use in the Mid-South agricultural region (Table 2.1). Other species commonly planted are winter wheat, *Triticum aestivum* L. (Poales: Poaceae); triticale, *Secale cereale* L. *x Triticum aestivum* L. (Poales: Poaceae); tillage radish, *Raphanus sativus* (L.) *var. niger* (Brassicales: Brassicaceae); and Austrian winter pea, *Pisum sativum* L. *subsp. arvense* (Fabales: Fabaceae).

Before or right at planting, cover crops are terminated with an herbicide or through mechanical tillage. Producers seeking weed control from cover crops, typically delay termination until right at planting in order for the cover crop to achieve the most biomass to shade out germinating weed seed (Montgomery et al. 2018, Mirsky et al. 2013, Norsworthy et al. 2012). This action can create a "Green Bridge" for insect pests from the cover crop to seedling crops planted into the vegetation (Hodgson et al. 2015, White et al. 2015, Lorenz and Goodson 2014). When soybean, *Glycine max* (L.) Merr. (Fabales: Fabaceae), is planted into a green cover crop, early season insect pests can move from the dying cover crop vegetation to the newly emerged seedlings in the field.

The pea leaf weevil, *Sitona lineatus* L. (Coleoptera: Curculionidae), is a pest that can move from legume cover crops to vegetative soybean plants. Adult pea leaf weevil establish shelter beds where they overwinter in secondary leguminous plants (Schotzko and O'Keeffe 1988) such as clovers, vetch, and winter pea cover crops. When the adult weevils exit their overwintering shelter, they seek a primary host site such as a pea or bean field (Fisher and O'Keeffe 1979; Landon et al. 1995). Winter pea cover crops provide an excellent host site for the first generation to feed and reproduce. Adult pea leaf weevils feed on the leaves of leguminous plants (Hoebeke and Wheeler 1985); whereas, the larvae feed upon the nodules containing the nitrogen-fixing bacteria, *Rhizobium leguminosarum* Frank (Rhizobiales: Rhizobiaceae) (Johnson and O'Keeffe 1981). These pests will feed on immature soybean seedlings causing major defoliation that leads to stand loss. Foliar applications of high rates of pyrethroid insecticides can provide good control against adult pea leaf weevils, but continual emergence of the developing larvae in the soil can lead to multiple costly applications (Lorenz and Goodson 2014). Neonicotinoid seed treatments applied to the seed coat before planting can provide control from multiple emergences of the pest (Cook et al. 2016, Cook and Gore 2014, Lorenz and Goodson 2014, Price et al. 2009).

Other early season pests affecting soybean planted behind winter annual cover crops include threecornered alfalfa hopper, *Spissistilus festinus* (Say) (Hemiptera: Membracidae); bean leaf beetle, *Ceratoma trifurcata* (Forster) (Coleoptera: Chrysomelidae); and the cutworm species complex, black cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae); and granulate cutworm, *Agrotis subterranea* (F.) (Lepidoptera: Noctuidae). Heliothines such as the corn earworm, *Helicoverpa zea* (Boddie)

(Lepidoptera: Noctuidae); and tobacco budworm, *Chloridea virescens* (F.) (Lepidoptera: Noctuidae), can use leguminous cover crops as an early season host in the spring (Dabney et al. 2001). Depending on the growth stage of other nearby hosts, vegetative soybean planted into the same field or adjacent fields can be used as an oviposition host by the moths that originally developed on the cover crop. Winter annual cover crops may provide sufficient habitat and protection for overwintering insects in production fields and may serve as early season hosts for pest insects during the early spring.

Monitoring early season insect pests in Mississippi soybean can be challenging making treatment decisions difficult (North et al. 2016). Neonicotinoid seed treatments are widely used and provide control throughout vegetative stages for most early season pests. These insecticides are systemic and control aboveground and belowground pests (Maienfisch et al. 2001). North et al. (2016) examined neonicotinoid seed treatment effects on soybean yield in a ten year study in the Mid-South. They found a mean yield response of 132.0 kg ha^{-1} when using a neonicotinoid seed treatment compared to using a seed treatment containing only a fungicide. Foliar sprays of pyrethroids can also be used on above ground insect pests and can provide control of threecornered alfalfa hopper, pea leaf weevil, bean leaf beetle, and cutworm species (Catchot et al. 2018). The objective of the current experiment was to determine the influence of winter annual cover crops on soybean insect pests and examine potential management strategies.

Materials and Methods

An experiment was conducted during the 2016 and 2017 growing seasons to determine the influence of annual winter cover crops and early season insect control strategies on soybean yield at two Mississippi locations. The R. R. Foil Plant Science

Research Center in Starkville, MS served as a location in the "Hills" region of MS located on the East side of the state, and the Mississippi State University Delta Research and Extension Center in Stoneville, MS served as a location in the "Delta" region of MS located on the West side of the state. Field trials were established on 8 row plots measuring 15.24 m long. Plots at the "Hills" location were planted on 0.97 m rows, whereas; plots at the "Delta" location were planted on 1.02 m rows. Other differences in the site locations were that the "Delta" soybean plots were irrigated, and irrigation was not possible at the "Hills" location.

To establish the field trial plots, the cover crop treatment was planted and incorporated into the soil during the month of October before each growing season. The cover crop seed were broadcast over plots at a rate of 78.62 kg ha^{-1} in an even distribution. In 2016 at the "Hills" location, a drag implement was used to incorporate the cover crop seed into the soil. In 2016 and 2017 at the "Delta" location and in 2017 at the "Hills" location, a roller implement was used to incorporate the cover crop seed into the soil. At approximately four weeks prior to soybean planting, a glyphosate application of 3.66 L ha^{-1} (Roundup®, Monsanto, St. Louis, MO) was used as a burndown application to kill the cover crops and the natural winter vegetation. In addition to chemical termination, plots were rolled with an agricultural roller implement to facilitate planting in 2017 at the "Hills" location and in 2016 and 2017 at the "Delta" location. Soybean seed, Asgrow® 4835, (Monsanto, St. Louis, MO) were planted using a tractor implemented with a John Deere® MaxEmerge® 1700 Rigid Integral 4 row wide pneumatic vacuum planter (Deere & Company, Moline, IL) during May of each growing season at a seeding rate of 271,810 plants ha^{-1} except for the increased seeding rate treatment.

Treatments were arranged in a factorial arrangement within a randomized complete block design. Each randomization of treatments was replicated four times at each location. Factor A consisted of two cover treatments, and Factor B consisted of six control method treatments. The two cover treatments were a cover crop blend of Austrian winter pea, *Pisum sativum* L. ssp. *arvense* (L.) (2016), or hairy vetch, *Vicia villosa* Roth (2017), tillage radish, *Raphanus sativus* L. var. *niger* J. Kern., and triticale, *S. cereale* L. *x Triticum aestivum* L., and an unplanted treatment in which plots were allowed to be naturally infested by winter weeds. The rates at which they were blended were weighted percentages of each at 33%, 22%, and 45% of the total mix, respectively. Treatments included an untreated control where only fungicide was applied to soybean seed, a foliar application of lambda-cyhalothrin at 109.61 ml ha^{-1} (Karate® Z, Syngenta Crop Protection, Greensboro, NC) applied with the burndown herbicide application, soybean seed treated with the neonicotinoid seed treatment thiamethoxam at 0.0778 mg ai/seed (CruiserMaxx®, Syngenta Crop Protection, Greensboro, NC) in 2016 or imidacloprid at 0.2336 mg ai/seed (Gaucho®, Bayer CropScience, Research Triangle Park, NC) in 2017, the lambda-cyhalothrin burndown application plus the neonicotinoid seed treatment, an in-furrow application of bifenthrin at 236.59ml/304.8 row m (Capture® LFR®, FMC Agricultural Solutions, Philadelphia, PA) applied during the planting of soybean seed, and a 50 percent increased seeding rate of 407,715 plants/ha. All soybean seed were treated with the fungicide mefenoxam and fludioxonil at 0.0092 mg/seed (ApronMaxx® RTA®, Syngenta Crop Protection, Greensboro, NC).

At the V3 growth stage, soybean plots were scouted for pea leaf weevil, three cornered alfalfa hopper, and bean leaf beetle during the 2017 growing season. These three pests were not present in observable levels during the 2016 growing season. Pests were counted per meter of row for each treatment combination on the second row of each plot. Also at the V3 growth stage in 2017, defoliation was estimated in each plot. After soybean plants matured, plots were mechanically harvested using a Kincaid 8XP plot combine with a weight system and seed weights were recorded (Kincaid Equipment Manufacturing, Haven, KS). Moisture was determined and seed yields corrected to 13% and recorded for each plot.

Insect count data from the 2017 growing season were analyzed using analysis of variance (PROC GLIMMIX, SAS® Version 9.4, SAS Institute, Cary, NC). Cover type, insect control method, and their interaction served as fixed effects in the model. Location and rep nested in location were treated as random effects. Degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$). Means are presented as total number of insects per m of row of each treatment and treatment combination.

Insect damage data from the 2017 growing season were analyzed using analysis of variance (PROC GLIMMIX, SAS® Version 9.4, SAS Institute, Cary, NC). Cover type, insect control method, and their interaction served as fixed effects in the model. Location and rep nested in location were treated as random effects. Degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$). Means are presented as mean percent defoliation of each treatment and treatment combination.

Yield data were analyzed using analysis of variance (PROC GLIMMIX, SAS® Version 9.4, SAS Institute, Cary, NC). Mean soybean yield was analyzed with previous cover type and insect control method as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. Degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$). Means are presented as soybean yield (kg ha^{-1}) of each treatment and treatment combination.

Results

During 2016 at both locations, no observable populations of aboveground insect pests were recorded in soybean plots. Relatively low numbers of pea leaf weevil, three cornered alfalfa hopper, and bean leaf beetle were observed in the 2017 growing season. Because numbers of each pest were relatively low, the analysis was conducted on all pest species together and only in 2017. No significant interaction existed between previous cover type and insect control method ($F = 0.17$; $df = 5, 83$; $P = 0.97$), and the main effect of previous cover type was not significant ($F = 0.51$; $df = 1, 83$; $P = 0.48$) in regards to mean total insects per 1 m of row. Significant differences in mean total insects per 1 m of row at the V3 growth stage were observed among insect control methods ($F = 7.78$; $df = 5, 83$; $P < 0.01$). The bifenthrin in-furrow, neonicotinoid seed treatment, and lambda-cyhalothrin plus neonicotinoid seed treatment resulted in significantly fewer insect pests than the untreated control (Figure 2.1). Additionally, both treatments that included a neonicotinoid seed treatment resulted in fewer insect pests than the lambda-cyhalothrin treatment, the increased plant population treatment, and the untreated control.

Due to no observable populations of aboveground insect pests being observed in soybean plots in 2016, defoliation ratings were not conducted during that growing season. Relatively low insect defoliation damage in soybean plots was recorded and analyzed in 2017. No significant interaction existed between previous cover type and insect control method (F = 1.11; df = 5, 77; P = 0.36), and the main effect of previous cover type was not significant (F = 3.05; df = 1, 77; P = 0.08) in regards to mean percent defoliation. Significant differences were observed in mean percent defoliation at the V3 growth stage among insect control methods (F = 3.16; df = 5, 77; P = 0.01). The lambda-cyhalothrin, increased plant population, bifenthrin in-furrow, neonicotinoid seed treatment, and lambda-cyhalothrin plus neonicotinoid seed treatment all resulted in significantly less defoliation at the V3 growth stage than the untreated control (Figure 2.2).

Soybean harvest data were collected at all field trial locations during both growing seasons. No significant interaction existed between previous cover type and insect control method (F = 0.68; df = 5, 165; P = 0.64), and the main effect of previous cover type was not significant (F = 3.32; df = 1, 165; P = 0.07) in regards to mean soybean yield. Significant differences between insect control methods for mean soybean yield were observed (F = 3.25; df = 5, 165; P <0.01). Plots treated with a neonicotinoid seed treatment or plots that received the lambda-cyhalothrin plus a neonicotinoid seed treatment had significantly higher yield than the soybean only treated with lambda-cyhalothrin and the untreated control (Figure 2.3). Soybean treated with the bifenthrin in-furrow did not significantly differ from soybean treated with any other control method treatments or the untreated control in regards to mean soybean yield. Additionally, soybean yields in the lambda-cyhalothrin plus a neonicotinoid seed treatment plots were not significantly different than soybean yield in the increased planting population plots. Soybean yields in plots that received the increased planting population treatment, lambda-cyhalothrin treatment, or the untreated control did not significantly differ from each other.

Discussion

Winter annual cover crops are occasionally planted before soybean in the Mid-South to improve soil health and shade out early season weed seed. Planting of cover crops can result in an insect carryover effect known as the "Green Bridge" where soybean pests feeding in the cover crop are retained in the field. Foliar pests such as the pea leaf weevil, three cornered alfalfa hopper, bean leaf beetle, and a few Lepidopteran species have the potential to be influenced by the use of winter annual cover crops before soybean planting. Control of these pests is possible through the use of neonicotinoid insecticides. In the Mid-South soybean growing region, these seed treatments have been shown to provide protection against early season pests and increase yields (North et al. 2016). Other regional studies across the United States report no yield benefits from the use of neonicotinoid seed treatments when used to target soybean pests of their respective locations (Seagraves and Lundgren 2012, Ohnesorg et al. 2009, Cox et al. 2006, and McCornack and Ragsdale 2006). To understand how neonicotinoid seed treatments and other early season control strategies affect insect pests in Mid-South soybean following winter annual cover crops, an experiment was conducted.

In the 2016 growing season, little to no aboveground insect pests were observed in the early growth stages of soybean plots planted in both locations. Relatively low numbers of pea leaf weevil, bean leaf beetle, and three cornered alfalfa hopper were observed during the early growth stages of soybean plots at both locations. The absence of large early season insect pest populations can most likely be attributed to terminating the cover crop four weeks prior to soybean planting which is the current recommendation by Mid-South entomologists. The "Green Bridge" phenomenon was not observed in this study indicated by the lack of significant differences in the cover crop main effect for insect pests and defoliation. A shorter window between the cover crops and soybean emergence may have increased the likelihood of having a larger infestation. This is clearly demonstrated when comparing defoliation with a previous study conducted in one of the same locations. Cook and Gore (2014) observed severe pea leaf weevil defoliation in soybean following a vetch cover crop in 2012. The pea leaf weevil defoliated untreated plots had a mean defoliation rating of almost 95%. Untreated soybean plots following a blended cover crop evaluated in our study in 2017 were defoliated at a rate of 6.25%.

The composition of the cover crop could have also affected insect infestations. Legume cover crops pose more of a risk of increasing pea leaf weevil in soybean (Cook et al. 2016, Cook and Gore 2014, Lorenz and Goodson 2014, Price et al. 2009). Our cover crop treatment was comprised of tillage radish, hairy vetch or Austrian winter pea, and triticale. The rates at which they were blended were weighted percentages of each at 22%, 33%, and 45% of the total mix respectively. With the legume species only making up a third of the blend, this cover crop may not have been as attractive as the one used in 2012 (Cook 2014). The presence of pea leaf weevil did indicate that the cover crop blend attracted soybean pests in 2017. Pea leaf weevil are usually only associated with soybean following legume cover crops. However, these relatively low numbers did not significantly differ among previous cover type treatments. This could be due to the low numbers or to the migratory habits of the insects. Plot sizes were double the normal size of field trials on these research stations, but movement among plots could have still happened.

Although relatively small numbers of early season insect pests occurred in 2017, the insect control methods did significantly differ in both total insect pests observed and defoliation damage. Neonicotinoid seed treatments reduced the number of early season insects compared to the untreated control, as did the bifenthrin in-furrow application. The bifenthrin in-furrow application did not differ from the lambda-cyhalothrin treatment and increased planting population which did not differ from the untreated control. The lambda-cyhalothrin treatment independently did not differ from the untreated control; therefore, it did not contribute to reducing the insect numbers in V3 soybean when combined with the use of a neonicotinoid seed treatment. Neonicotinoid seed treatments are the best option to reduce aboveground insect numbers in early season soybean.

All control methods reduced the mean percent defoliation caused by early season insects in V3 soybean defoliation. The untreated control was only defoliated at a mean damage percentage of around 7%. This damage was double the damage percentages observed in other treatments. Seven percent defoliation most likely would not affect soybean yield at the end of the growing season, so these results may have no economic significance. However, it is likely that these differences would also be observed at higher levels of defoliation under more severe pest pressure.

After soybean plots were mechanically harvested, significant differences were observed between control methods over all four siteyears. The neonicotinoid seed treatment had a significantly higher yield than the untreated control at a difference of 186.33 kg ha^{-1}. This yield increase could have been due to protection from above-ground pests such as pea leaf weevil, bean leaf beetle, and three cornered alfalfa hopper. However, due to low densities of above-ground pests and defoliation levels, it is likely that differences can be attributed to other pests not accounted for with the sampling procedures used in this study. Pests that occur below the soil surface, such as wireworms, southern corn rootworm, and white grubs, are difficult to monitor but are common pests of Mid-South soybean. These pests are heavily influenced by tillage and the presence of grasses and other non-crop plants within fields during non-cropping months (Hesler et al. 2018). This scenario is more likely because the three highest yielding treatments have activity on soil pests. The neonicotinoid seed treatments may have protected the vegetative soybean from these in addition to any above-ground pests influenced by the cover crop. These data show that neonicotinoid seed treatments are valuable in Mid-South soybean systems, and reduce damage from potential insect pests influenced by winter annual cover crops. Additional studies should be conducted to examine influences of cover crops on the early season pest complex in soybean. These experiments should reduce the termination timing of the cover crop to right at planting and be made up of large scale plots.

Table 2.1 Top cover crop species in the Mid-South agricultural region (Clark 2008).

Common Name	**Scientific Name**	**Order**	**Family**
Hairy Vetch	*Vicia villosa* Roth	Fabales	Fabaceae
Subterranean Clover	*Trifolium subterraneum* L.	Fabales	Fabaceae
Berseem Clover	*Trifolium alexandrinum* L.	Fabales	Fabaceae
Crimson Clover	*Trifolium incarnatum* L.	Fabales	Fabaceae
Annual Ryegrass	*Lolium multiflorum* Lam.	Poales	Poaceae
Cereal Rye	*Secale cereale* L.	Poales	Poaceae
Sorghum-Sudangrass Hybrid	*Sorghum bicolor* (L.) *x S. bicolor* (L.) *var. sudanese*	Poales	Poaceae
Cowpea	*Vigna unguiculata* (L.)	Fabales	Fabaceae
Sweetclover	*Melilotus officinalis* (L.)	Fabales	Fabaceae
Buckwheat	*Fagopyrum esculentum* Moench	Caryophyllales	Polygonaceae

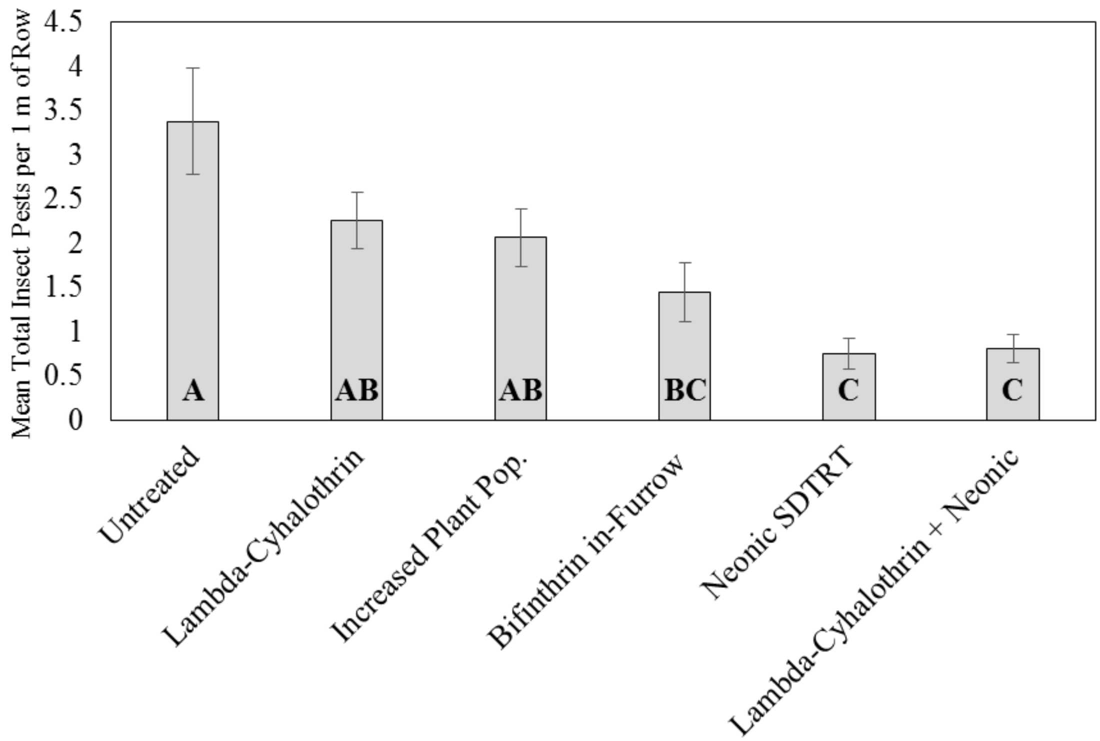

Figure 2.1 Mean total of insect pests per 1 m of row at the V3 growth stage for each insect control method during the 2017 growing season.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean. Total of insect pests include pea leaf weevil, bean leaf beetle, and three cornered alfalfa hopper.

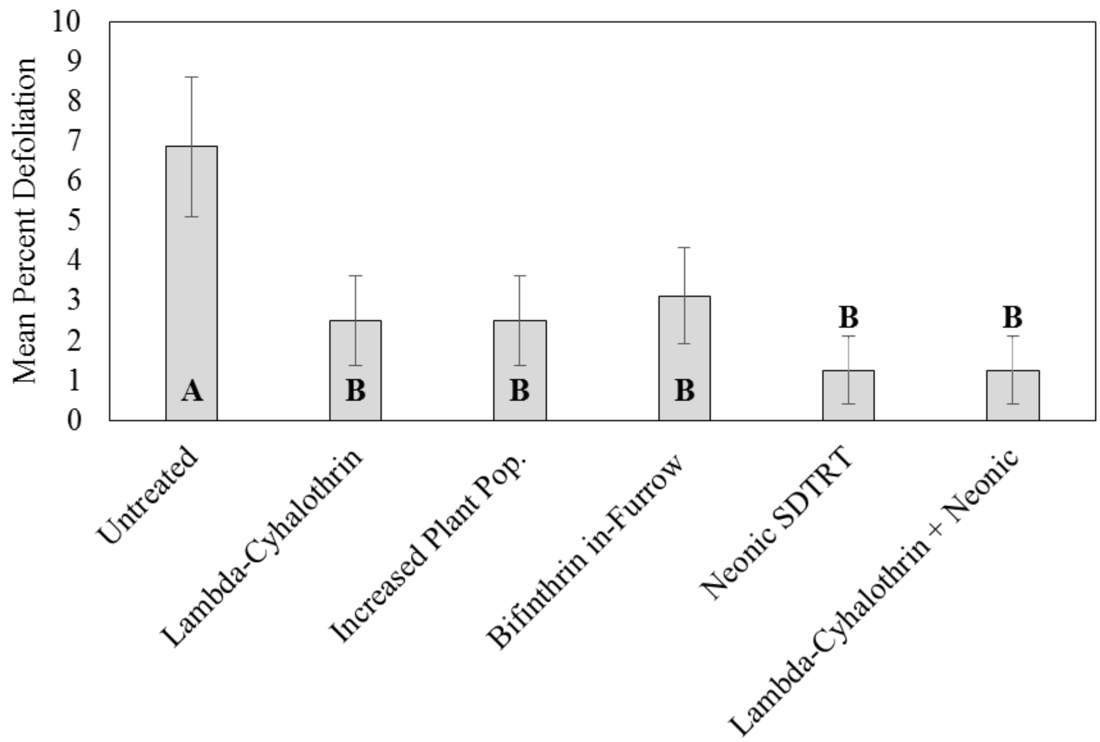

Figure 2.2 Mean percent defoliation at the V3 growth stage for each insect control method during the 2017 growing season.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

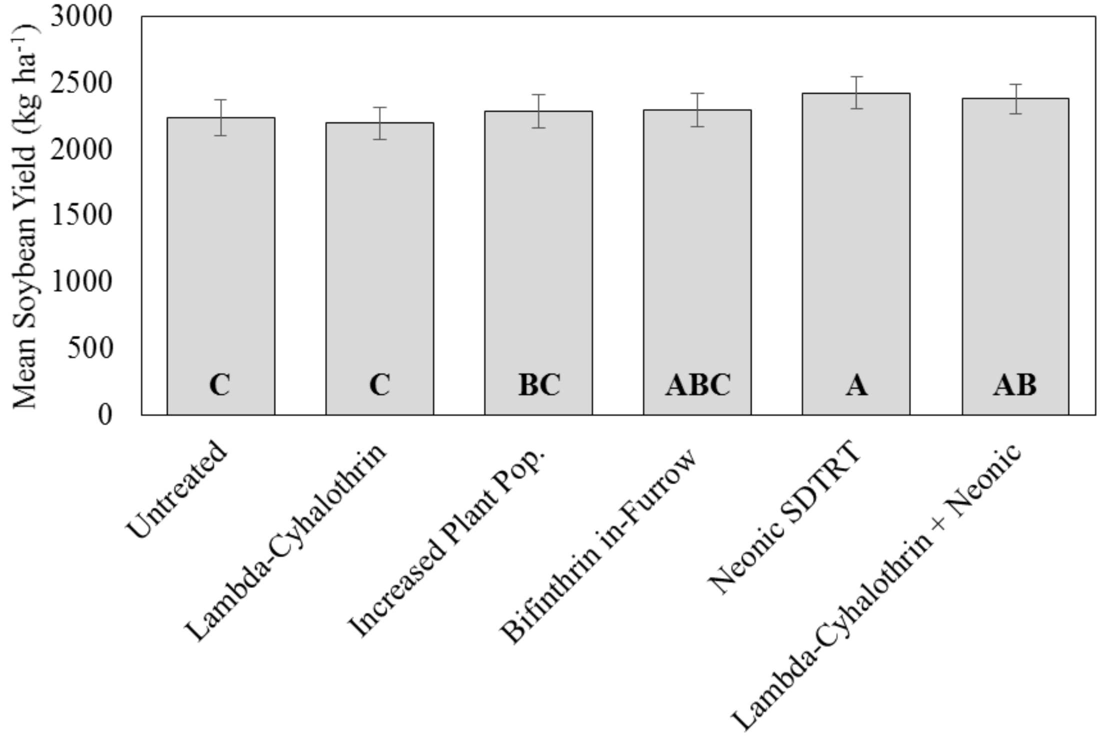

Figure 2.3 Mean soybean yield for each insect control method.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

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CHAPTER III

INFLUENCE OF WINTER ANNUAL COVER CROPS, TERMINATION TIMING, AND NEONICOTINOID SEED TREATEMENTS ON EARLY SEASON INSECT PESTS OF SOYBEAN

Introduction

Producers looking for cultural practices to improve soil health and suppress early season weeds often implement winter annual cover crops into their cropping systems (Clark 2008, USDA-NRCS 2014). Cover crop plantings can range from single species plantings to mixes of legumes, grasses, and forbs (USDA-NRCS 2014). Clark (2008) lists eight cover crop species as the top species to use in the Mid-South agricultural region (Table 3.1). Other species commonly planted are winter wheat, *Triticum aestivum* L. (Poales: Poaceae), triticale, *Secale cereale* L. *x Triticum aestivum* L. (Poales: Poaceae), tillage radish, *Raphanus sativus* (L.) *var. niger* (Brassicales: Brassicaceae), and Austrian winter pea, *Pisum sativum* L. *subsp. Arvense* (Fabales: Fabaceae).

Cover crops are usually planted in the fall months and are allowed to accumulate biomass from the time they are planted until early spring (Clark 2008). Cover crops are usually terminated through the use of a herbicide or through mechanical action. Termination timing is determined by the intended agronomic benefit of the cover crop. To achieve the best early season weed suppression, producers are encouraged to delay termination to as close to planting as they can (Norsworthy et al. 2012, Mirsky et al. 2013, Montgomery et al. 2018). This allows cover crops to maximize biomass and shade out potential germinating weed seed in the soil (Norsworthy et al. 2012, Mirsky et al. 2013, Montgomery et al. 2018). Terminating a cover crop close to planting can enable phytophagous insects to cross a "Green Bridge" into the cultivated cash crop (Lorenz and Goodson 2014, Hodgson et al. 2015, White et al. 2015). If the previously planted cover crop hosts the same insect pests as the cultivated cash crop, delaying termination can lead to serious pest problems.

One insect pest associated in legume cover crops and soybean, *Glycine max* (L.) Merr. (Fabales: Fabaceae), is the pea leaf weevil, *Sitona lineatus* L. (Coleoptera: Curculionidae). This pest feeds on leguminous plants in the late fall where it forms overwinter shelters (Schotzko and O'Keeffe 1988). In the spring months, adult pea leaf weevil exit these fields and look for primary hosts such as pea fields (Fisher and O'Keeffe 1979; Landon et al. 1995). Austrian winter pea is a commonly used cover crop that can attract pea leaf weevil to crop fields. The adult pea leaf weevil will feed on the leaves of the pea plants (Hoebeke and Wheeler 1985), whereas; the larvae feed upon the nodules containing the nitrogen-fixing bacteria, *Rhizobium leguminosarum* Frank (Rhizobiales: Rhizobiaceae) underground in the root nodules of the plants (Johnson and O'Keeffe 1981). Larvae pupate underground beneath the pea plants (Johnson and O'Keeffe 1981, Hoebeke and Wheeler 1985). When soybean are planted behind peas or other leguminous hosts, adult pea leaf weevils can move from the dying peas to the soybean seedlings. Newly emerging adults from the soil can also attack the young soybean plants (Lorenz and Goodson 2014). Foliar applications of pyrethroids can effectively control adult pea leaf weevil feeding on soybean foliage, but a neonicotinoid seed treatment is needed to offer continued control from the emerging adults from the soil (Price et al. 2009, Cook and Gore 2014, Lorenz and Goodson 2014, Cook et al. 2016).

Other early season pests that may be influenced by winter annual cover crops planted before soybean include three cornered alfalfa hopper, *Spissistilus festinus* (Say) (Hemiptera: Membracidae), bean leaf beetle, *Ceratoma trifurcata* (Forster) (Coleoptera: Chrysomelidae), and the cutworm species complex, black cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae), granulate cutworm, *Agrotis subterranea* (F.) (Lepidoptera: Noctuidae), and variegated cutworm, *Peridroma saucia* (Hubner) (Lepidoptera: Noctuidae). Noctuids such as the corn earworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) and tobacco budworm, *Chloridea virescens* (F.) (Lepidoptera: Noctuidae), can use leguminous cover crops as an early season host in the spring (Dabney et al. 2001). Depending on the growth stage of other nearby hosts, vegetative soybean planted into the same field can be used as an ovipositional host by the moths that originally developed on the cover crop. Winter annual cover crops provide habitat for overwintering in production fields as well as suitable early season hosts for early season insect pests.

Scouting for early season insect pests in soybean can be difficult as some infestations are not detected until damage is observed. Neonicotinoid seed treatments provide preventative protection against above- and below-ground pests through the systemic action of the pesticide (Maienfisch et al. 2001). These treatments are applied to the seed coat before planting. In the Mid-South region of the United States, North et al. (2016) showed a mean increase of 132.0 kg ha^{-1} on soybean yield over a ten year span when using a neonicotinoid seed treatment compared to seed only treated with fungicide. Neonicotinoid seed treatments are under public scrutiny due to alleged links to pollinator decline making their economic impact important into registration decisions. How these seed treatments operate in all soybean production systems should be evaluated. The objective of the current research was to determine the influence of winter annual cover crops, termination timing, and neonicotinoid seed treatments on soybean insect pests and yield.

Materials and Methods

An experiment was conducted in the growing seasons of 2016 and 2017 to determine the influence of annual winter cover crops, termination timings, and seed treatments on soybean insect pests in two Mississippi locations. In 2016 and 2017, the R. R. Foil Plant Science Research Center in Starkville, MS served as a location in the "Hills" region of MS located on the East side of the state; and in 2017 the Mississippi State University Delta Research and Extension Center in Stoneville, MS served as a location in the "Delta" region of MS located on the West side of the state. Field trials were establish on 4 row plots measuring 3.86 m wide by 15.24 m long. Plots at the "Hills" location were planted on 0.97 m rows, whereas; plots at the "Delta" location were planted on 1.02 m rows. Other differences in the site locations were that the "Delta" soybean plots were irrigated, and irrigation was not possible at the "Hills" location.

To establish the field trial plots, the cover crop treatments were planted and incorporated into the soil during the month of October before each growing season. The cover crop seed were broadcast over plots at a rate of 78.62 kg ha^{-1} in an even distribution. In 2016 at the "Hills" location, a drag implement was used to incorporate the cover crop seed into the soil. In 2017 at the "Delta" and "Hills" locations, a roller implement was used to incorporate the cover crop seed into the soil. Cover crops and the natural winter vegetation were chemically terminated with a glyphosate application of 3.66 L ha^{-1} at the appropriate termination timing treatments. In addition to chemical termination, plots were rolled with an agricultural roller implement to facilitate planting in 2016 at the "Hills" location and at 2016 and 2017 at the "Delta" location. Soybean seed, Asgrow® 4835, (Monsanto, St. Louis, MO) was planted using a tractor implemented with a John Deere® MaxEmerge® 1700 Rigid Integral 4 row wide pneumatic vacuum planter (Deere & Company, Moline, IL) during May of each growing season at a seeding rate of 271,810 plants ha^{-1}.

Treatments were arranged in a factorial arrangement within a randomized complete block design. Each randomization of treatments was replicated four times at each location. Factor A consisted of three cropping system treatments, Factor B consisted of three termination timings, and Factor C consisted of insecticidal and non-insecticidal seed treatments. The three previous cover type treatments were a cover crop blend of Austrian winter pea, *Pisum sativum* L. ssp. *arvense* (L.) Poir or hairy vetch, *Vicia villosa* Roth, tillage radish, *Raphanus sativus* L. var. *niger* J. Kern., and triticale, *S. cereale* L. *x Triticum aestivum* L., a cover crop treatment of winter wheat, *Triticum aestivum* L., and an unplanted treatment in which plots were allowed to be naturally infested with winter weeds. Cover crop termination timings were approximately 6, 4, and 2 weeks prior to planting. The seed treatments used for Factor C were an untreated control where only fungicide was applied to soybean seed and a treatment where soybean seed were treated with the neonicotinoid seed treatment CruiserMaxx® (thiamethoxam, 0.0778 mg/seed, Syngenta Crop Protection, Greensboro, NC) in 2016 and Gaucho® (imidacloprid, 0.2336 mg/seed, Bayer CropScience, Research Triangle Park, NC) in 2017. All soybean seed were treated with the fungicide ApronMaxx® RTA® (mefenoxam and fludioxonil, 0.0092 mg/seed, Syngenta Crop Protection, Greensboro, NC).

At the V3 growth stage, soybean plots were scouted for pea leaf weevil, three cornered alfalfa hopper, and bean leaf beetle during the 2017 growing season. These three pests were not present in observable levels during the 2016 growing season. Pests were counted per meter of row for each treatment combination on the second row of each plot. Also at the V3 growth stage in 2017, a defoliation rating was estimated for each plot. After soybean plants matured, plots were mechanically harvested using a Kincaid 8XP plot combine with a weigh system and seed weights were recorded (Kincaid Equipment Manufacturing, Haven, KS). Moisture was determined and seed yields corrected to 13% and recorded for each plot.

Insect count data from the 2017 growing season were analyzed using PROC GLIMMIX of SAS® (Version 9.4, SAS Institute, Cary, NC). Previous cover type, termination timing, and seed treatment served as fixed effects in the model. Location and replication nested in location were treated as random effects. Degrees of freedom were calculated using the Kenwood-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$). Means are presented as total number of insects per m of row of each treatment and treatment combination.

Insect damage data from the 2017 growing season were analyzed using PROC GLIMMIX of SAS® (Version 9.4, SAS Institute, Cary, NC). Previous cover type, termination timing, and seed treatment served as fixed effects in the model. Location and replication nested in location were treated as random effects. Degrees of freedom were calculated using the Kenwood-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference (α = 0.05). Means are presented as mean percent defoliation of each treatment and treatment combination.

Yield data were analyzed using PROC GLIMMIX of SAS® (Version 9.4, SAS Institute, Cary, NC). Mean soybean yield was analyzed with previous cover type, termination timing, and seed treatment as fixed effects in the model. Siteyear and replication nested in siteyear were treated as random effects. Degrees of freedom were calculated using the Kenwood-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference (α = 0.05). Means are presented as soybean yield (kg ha^{-1}).

Results

During 2016 at both locations, no observable populations of aboveground insect pests were recorded in soybean plots. Relatively low numbers of pea leaf weevil, three cornered alfalfa hopper, and bean leaf beetle were observed in the 2017 growing season. Because numbers of each pest were relatively low, the analysis was conducted on all pest species together and only in 2017. No significant interactions existed between previous cover type, termination timing, and seed treatment (F = 1.63; df = 4, 125; P = 0.17), previous cover type and termination timing (F = 1.83; df = 4, 125; P = 0.13), previous cover type and seed treatment type (F = 2.70; df = 2, 125; P = 0.07), and termination timing and seed treatment type (F = 0.16; df = 2, 125; P = 0.85) in regards to mean total insects per 1 m of row at the V3 growth stage. No significant differences were observed among the main effects of previous cover type (F = 2.17; df = 2, 125; P = 0.12), termination timing (F = 0.81; df = 2, 125; P = 0.45), and seed treatment type (F = 2.59; df = 1, 125; P = 0.11) in regards to mean total insects per 1 m of row at the V3 growth stage.

Due to no observable populations of aboveground insect pests were recorded in soybean plots in 2016, defoliation ratings were not conducted during that growing season. Relatively low insect defoliation damage in soybean plots was recorded and analyzed in 2017. No significant interaction existed between previous cover type, termination timing, and seed treatment (F = 0.86; df = 4, 119; P = 0.49), previous cover type and termination timing (F = 1.26; df = 4, 119; P = 0.29), previous cover type and seed treatment type (F = 0.17; df = 2, 119; P = 0.84), and termination timing and seed treatment type (F = 1.21; df = 2, 119; P = 0.30) in regards to mean percent defoliation at the V3 growth stage. No significant differences were observed among the main effects of previous cover type (F = 0.06; df = 2, 119; P = 0.94) and termination timing (F = 0.75; df = 2, 119; P = 0.48) in regards to mean percent defoliation at the V3 growth stage. Significant differences in mean percent defoliation at the V3 growth stage were observed among seed treatments (F = 12.93; df = 1, 119; P <0.01). The soybean plots treated with a neonicotinoid seed treatment had significantly less defoliation than the untreated control (Figure 3.1).

Soybean harvest data were collected at all field trial locations in both growing seasons. No significant interactions existed between previous cover type, termination timing, and seed treatment (F = 1.54; df = 4, 187; P = 0.19), previous cover type and seed treatment type (F = 1.85; df = 2, 187; P = 0.16), previous cover type and termination timing (F = 1.19; df = 4, 187; P = 0.32), and termination timing and seed treatment type (F = 0.49; df = 2, 187; P = 0.61) in regards to mean soybean yield. No significant differences were observed with the main effect of termination timing (F = 0.96; df = 2, 187; P = 0.38) in regards to mean yield of soybean. Significant differences were observed among the main effects of previous cover types (F = 9.61; df = 2, 187; P <0.01) seed treatment types (F =

5.36; *df* = 1, 187; *P* = 0.02) in regards to mean yield of soybean. The soybean plots planted behind the cover crop blend had significantly higher yields than the soybean plots planted behind the winter wheat cover crop and behind the natural winter vegetation (Figure 3.2). The yield of soybean plots planted behind winter wheat did not significantly differ from the yield of soybean plots planted behind natural winter vegetation. Soybean planted with a neonicotinoid seed treatment had a significantly higher yield than the untreated control (Figure 3.3).

Discussion

When implementing winter annual cover crops into soybean field rotational schemes, termination timing is usually based off of agronomic decisions. To inhibit germination of early season weed seed, cover crop termination is often delayed until right before planting (Montgomery et al. 2018, Mirsky et al. 2013). The downside of this practice is that it can create a "Green Bridge" for phytophagous insects to move from the cover crop to the cash crop planted behind it (Hodgson et al. 2015, White et al. 2015, Lorenz and Goodson 2014). The "Green Bridge" phenomenon was not observed in this study indicated by the lack of significant differences in the cover crop main effect for insect pests and defoliation. If insect pests are present and move from cover crops into immature soybean fields that are not protected with a neonicotinoid seed treatment, multiple applications of foliar insecticides may be needed to protect the young crop (Lorenz and Goodson 2014). Neonicotinoids can provide yield benefits to soybean in the Mid-Southern United States (North et al. 2016), but other studies in different regions of the country report little to no benefit (Seagraves and Lundgren 2012, Ohnesorg et al. 2009, Cox et al. 2006, and McCornack and Ragsdale 2006).

In the 2016 growing season, little to no aboveground insect pests were observed in the early growth stages of soybean plots planted in both locations. Relatively low numbers of pea leaf weevil, bean leaf beetle, and three cornered alfalfa hopper were observed during the early growth stages of soybean plots at both locations. The absence of large early season insect pest populations can most likely be attributed to the small plot size within the study and the composition of the cover crop blend. Plots were made up of only four rows measuring either 96.52 cm or 101.3 cm in width. Legume cover crops pose more of a risk of increasing pea leaf weevil in soybean (Cook et al. 2016, Cook and Gore 2014, Lorenz and Goodson 2014, Price et al. 2009). Our blended cover crop treatment was comprised of tillage radish, hairy vetch or Austrian winter pea, and triticale. The rates at which they were blended were weighted percentages of each at 22%, 33%, and 45% of the total mix respectively. With the legume species only making up a third of the blend, this cover crop blend as well as the winter wheat cover crop may not have been very attractive to early season soybean pests. The presence of pea leaf weevil did indicate that the cover crop blend attracted soybean pests in 2017. Pea leaf weevil are usually only associated with soybean following legume cover crops. However, these relatively low numbers did not significantly differ among previous cover type treatments. This could be due to the small plot size and the migratory habits of the insects.

Although relatively small numbers of early season insect pests in 2017, the seed treatments used did significantly differ in mean percent defoliation damage. Neonicotinoid seed treatments had significantly less damage than the untreated control (Figure 3.1). The untreated control was only defoliated at a mean damage percentage of 2.25%. The level of defoliation damage would not affect soybean yield at the end of the growing season, so these results may have no economic significance. Cook and Gore (2014) observed severe pea leaf weevil defoliation in soybean following a vetch cover crop in 2012. The pea leaf weevil defoliated untreated plots at a mean defoliation rating of almost 95%. Untreated soybean plots following a blended cover crop evaluated in our study in 2017 were defoliated at a rate of 2.08%.

After soybean plots were mechanically harvested, significant differences were observed between previous cover types over all four siteyears (Figure 3.2). Soybean following the blended cover crop had significantly higher yields than soybean planted behind winter wheat or natural winter vegetation. The blended cover crop must have provided an agronomic benefit to the soybean that the other two cover treatments did not. The blend contained elements not present in the other two treatments: a legume species and tillage radish. Hairy vetch and Austrian winter pea may have provided nitrogen through nitrogen fixation to the soybean plants early in their development that helped increase yield at the end of the season. The tillage radish could have reduced soil compaction in those plots allowing for roots to move deeper through the soil and allowed for better water penetration to benefit those plants.

Significant differences were also observed between seed treatments in regards to mean yield of soybean (Figure 3.3). The neonicotinoid seed treatment provide a yield increase of 84.00 kg ha^{-1}. This yield increase could have come from protection from aboveground pests such as pea leaf weevil, three cornered alfalfa hopper, and bean leaf beetle. Belowground pests were not accounted for within plots. Wireworms and white grubs are occasionally belowground pests in Mid-South soybean and are influenced by tillage and the presence of grasses and other non-crop plants within fields during non-cropping months (Hesler et al. 2018). Protection from belowground pests could have also contributed to the yield increase provide by the neonicotinoid seed treatment. These data show that neonicotinoid seed treatments are valuable in Mid-South soybean systems, and reduce damage from potential insect pests influenced by winter annual cover crops. Additional studies should be conducted to examine influences of cover crops on the early season pest complex in soybean. Species composition of the cover crops and size of the plots should be strategically planned.

Table 3.1 Top cover crop species in the Mid-South agricultural region (Clark 2008).

Common Name	**Scientific Name**	**Order**	**Family**
Hairy Vetch	*Vicia villosa* Roth	Fabales	Fabaceae
Subterranean Clover	*Trifolium subterraneum* L.	Fabales	Fabaceae
Berseem Clover	*Trifolium alexandrinum* L.	Fabales	Fabaceae
Crimson Clover	*Trifolium incarnatum* L.	Fabales	Fabaceae
Annual Ryegrass	*Lolium multiflorum* Lam.	Poales	Poaceae
Cereal Rye	*Secale cereale* L.	Poales	Poaceae
Sorghum-Sudangrass Hybrid	*Sorghum bicolor* (L.) *x S. bicolor* (L.) *var. sudanese*	Poales	Poaceae
Cowpea	*Vigna unguiculata* (L.)	Fabales	Fabaceae
Sweetclover	*Melilotus officinalis* (L.)	Fabales	Fabaceae
Buckwheat	*Fagopyrum esculentum* Moench	Caryophyllales	Polygonaceae

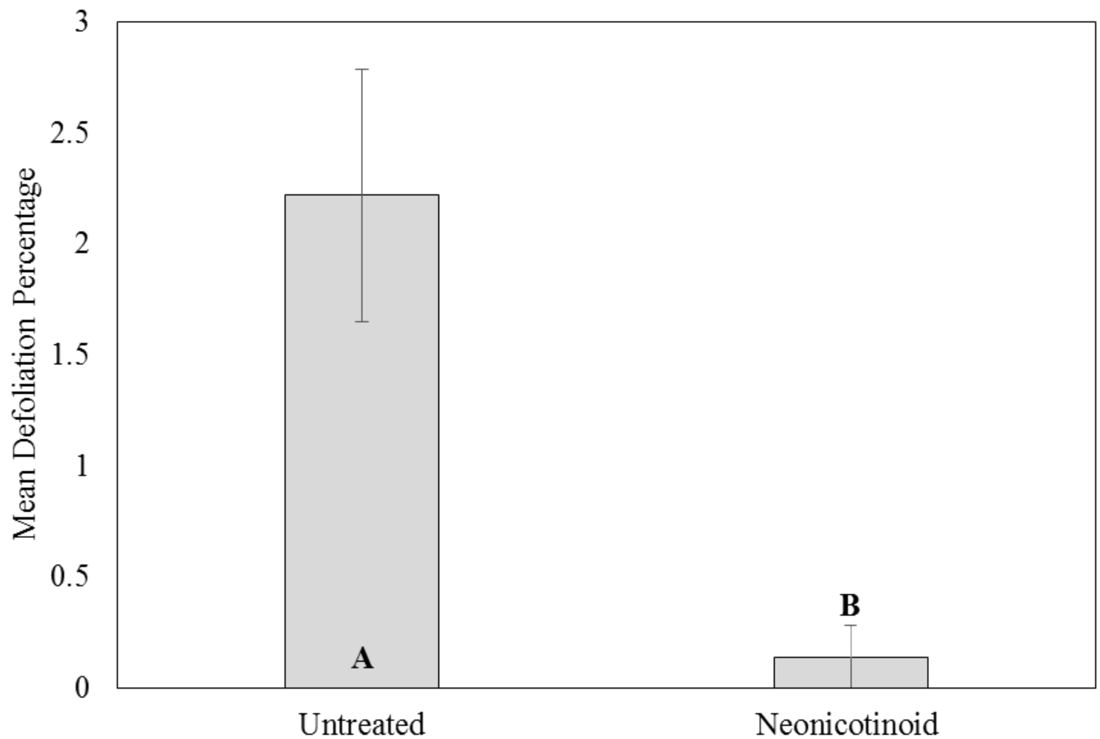

Figure 3.1 Mean percent defoliation at the V3 growth stage for each seed treatment during the 2017 growing season.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

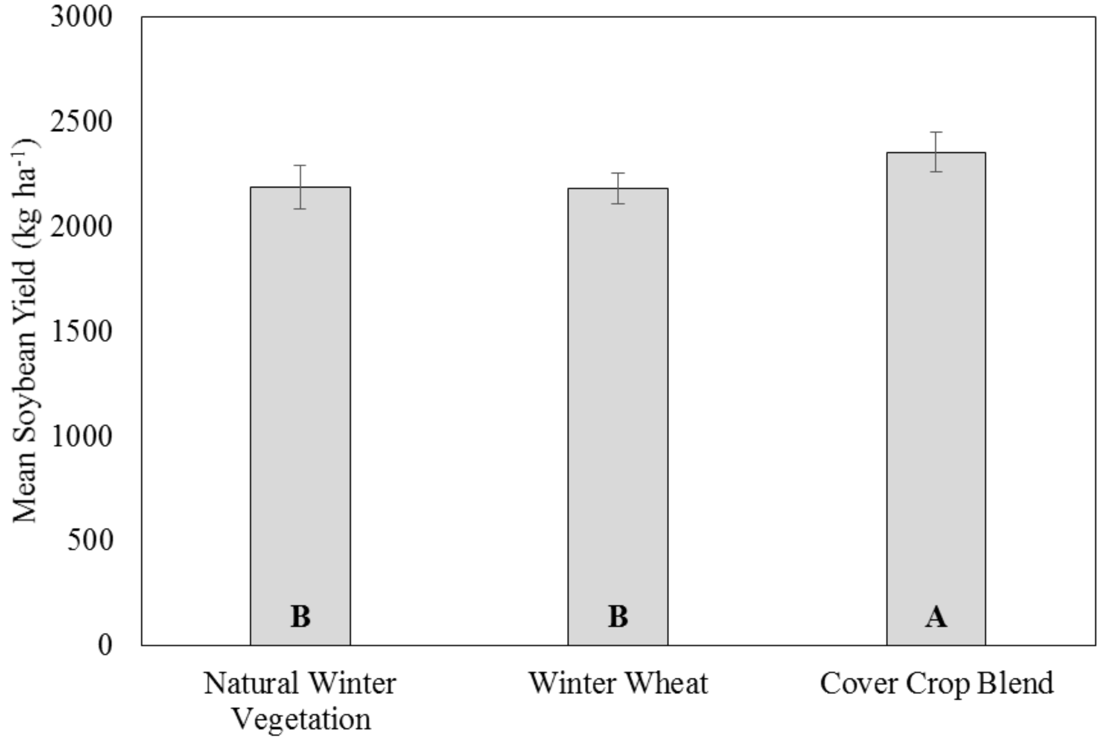

Figure 3.2 Mean soybean yield for each previous cover type.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

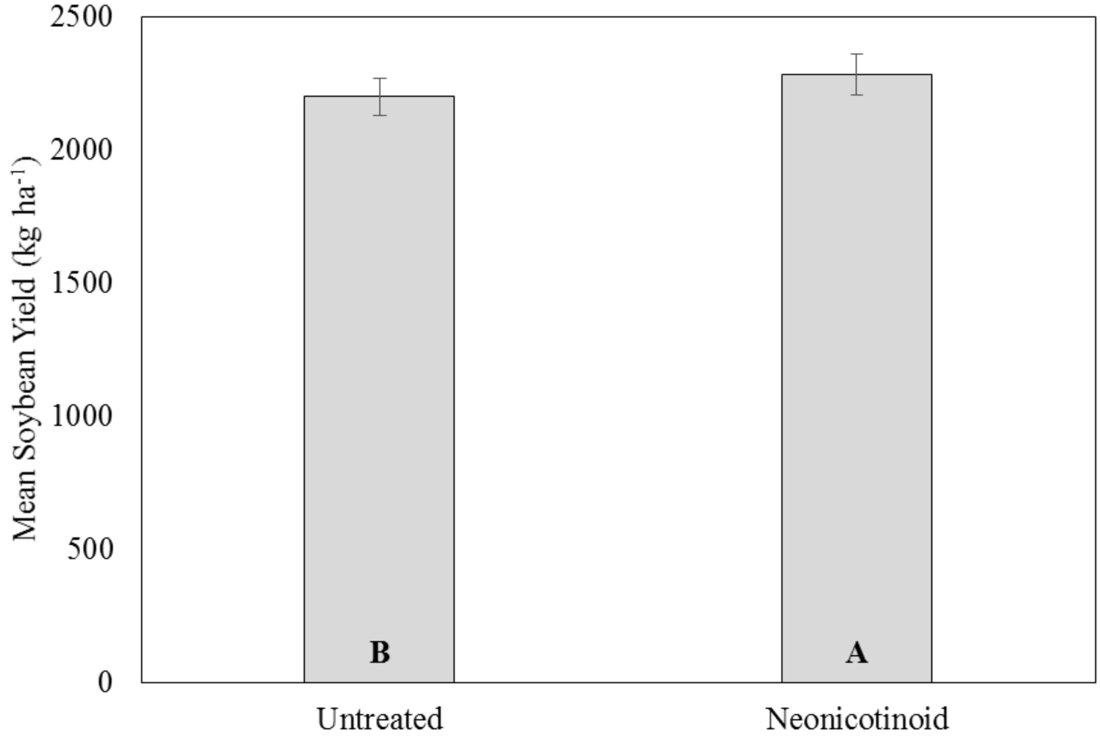

Figure 3.3 Mean soybean yield for each seed treatment.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

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CHAPTER IV

INFLUENCE OF VARIOUS WINTER COVER CROP SPECIES ON EARLY SEASON INSECT PESTS OF MISSISSIPPI SOYBEAN

Introduction

The practice of planting winter annual cover crops before cash crops is an increasing trend to provide soil health benefits and early season weed suppression (Clark 2008, USDA-NRCS 2014). In these systems cover crop seed is broadcasted or drilled into fields during the fall. From fall to spring, cover crops grow and increase in size allowing them to occupy field space that would have normally been occupied by natural winter vegetation. To increase biomass and maximize agronomic benefits, cover crops are sometimes terminated close to or immediately after planting (Mirsky et al. 2013, Montgomery et al. 2018). This delay can lead to insect pest issues in the early stages of the succeeding cash crop (Lorenz and Goodson 2014).

The movement of insect pests from winter cover crops to succeeding cash crops is often referred to as the "Green Bridge" (Lorenz and Goodson 2014, Hodgson et al. 2015, White et al. 2015). Phytophagous insects utilizing the cover crop as an early season host will stay in the field and move onto the seedling cash crop if it is a compatible host. With a large variety of cover crop species being available to provide various agronomic benefits to soybean, *Glycine max* (L.) (Fabales: Fabaceae), it is important to know which species can harbor early season pests.

Winter wheat, *Triticum aestivum* L. (Poales: Poaceae), and triticale, *Secale cereale* L. *x Triticum aestivum* L. (Poales: Poaceae), are two grass species that can be utilized as cover crops before soybean. They provide early season weed control by shading out weed seed and preventing germination (Clark 2008). These grass species also scavenge nitrogen and other nutrients from the soil and make it available again after termination (Clark 2008, Kladivko and Fisher 2011). The roots of these grass cover crops can stabilize soil particles and prevent erosion by not letting the soil leave the field during heavy rainfall (USDA-NRCS 2012, Clark 2008. Winter wheat is a host of the three cornered alfalfa hopper (Wildermuth 1915). These sucking pests can have an impact on early season soybean fields by girdling plants that can reduce stands through breakage (Cook et al. 2014). A winter cover crop of winter wheat could provide an early season host for this pest and allow it to be introduced to soybean planted into it.

Legume cover crops are often implemented in systems that benefit subsequent crops from their ability to fix atmospheric nitrogen (USDA-NRCS 1998). Soybean producers incorporate legumes for other benefits such as weed control (Clark 2008). Their ability to grow and accumulate biomass quickly makes them excellent early season weed suppressors (Clark 2008). Two leguminous cover crops that are often used are hairy vetch, *Vicia villosa* Roth (Fabales: Fabaceae), and Austrian winter peas, *Pisum sativum* L. *subsp. Arvense* (Fabales: Fabaceae) (Clark 2008). They are also utilized for erosion control and compaction prevention (Clark 2008). Leguminous cover crops can host many early season soybean pests.

The pea leaf weevil, *Sitona lineatus* L. (Coleoptera: Curculionidae), is often associated with legume cover crops and soybean (Lorenz and Goodson 2014). Adult pea leaf weevils overwinter in fields of leguminous plants and seek out pea fields as early season hosts (Fisher and O’Keeffe 1979; Landon et al. 1995). Larvae develop underground and can emerge as adults into newly planted soybean fields causing severe defoliation when untreated (Lorenz and Goodson 2014). Bean leaf beetle, *Ceratoma trigurcata* (Forster) (Coleoptera: Chrysomelidae), also overwinters in legumes; therefore, legume cover crops can attract the defoliating beetles to soybean fields (Funderburk et al. 1999). Three cornered alfalfa hopper overwinter in many species used as cover crops (Wildermuth 1915) and can have impacts on stands of early season soybean (Cook et al. 2014). Lepidopteran pests including cutworms, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae), *Agrotis subterranea* (F.) (Lepidoptera: Noctuidae), and *Peridroma saucia* (Hubner) (Lepidoptera: Noctuidae) and heliothines, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) and *Chloridea virescens* (F.) (Lepidoptera: Noctuidae), will utilize a legume cover crop as an early season host (Dabney et al. 2001, Leonard et al. 1994). This can result in emerging moths being in a soybean field where they may lay eggs on the soybean plants. Cutworm larvae can use cover crop residue as shelter and trim immature soybean plants at night (Catchot et al. 2018).

Cover crops can be made up of multispecies blends. It is important to understand the roles of each species within the cover crop in regards to insect pest attractiveness and agronomic benefits. In order to determine how different species of cover crops affect early season pests in Mississippi soybean, an experiment was conducted.

Materials and Methods

An experiment was conducted in 2016 and 2017 to determine the influence of various winter cover crops on soybean insect pests in two Mississippi locations. The R. R. Foil Plant Science Research Center in Starkville, MS served as a location in the "Hills" region of MS located on the East side of the state, and the Mississippi State University Delta Research and Extension Center in Stoneville, MS served as a location in the "Delta" region of MS located on the West side of the state. Field trials were established on 8 row plots measuring 15.24 m long. Plots at the “Hills” location were planted on 0.97 m rows, whereas; plots at the “Delta” location were planted on 1.02 m rows. Other differences in the site locations were that the “Delta” soybean plots were irrigated, and irrigation was not possible at the “Hills” location.

To establish the field trial plots, the cover crop treatment was planted and incorporated into the soil during the month of October before each growing season. Each cover crop seed was broadcast over plots at a rate of 78.62 kg ha^{-1} in an even distribution. In 2016 at the “Hills” location, a drag implement was used to incorporate the cover crop seed into the soil. In 2016 and 2017 at the “Delta” location and in 2017 at the “Hills” location, a roller implement was used to incorporate the cover crop seed into the soil. At approximately four weeks prior to soybean planting, a glyphosate application of 3.66 L ha^{-1} was used as a burndown application to kill the cover crops and the natural winter vegetation with and without the termination timed insecticide treatment. In addition to chemical termination, plots were rolled with an agricultural roller implement to facilitate planting in 2017 at the “Hills” location and at 2016 and 2017 at the “Delta” location. Soybean seed, Asgrow® 4835, (Monsanto, St. Louis, MO) were planted using a tractor implemented with a John Deere® MaxEmerge® 1700 Rigid Integral 4 row wide pneumatic vacuum planter (Deere & Company, Moline, IL) during May of each growing season at a seeding rate of 271,810 plants ha^{-1} except for the increased seeding rate treatment.

Treatments were arranged in a randomized complete block design. Each randomization of treatments was replicated four times at each location. Six previous cover treatments were used that included winter wheat, triticale, Austrian winter pea, hairy vetch, a cover crop blend of Austrian winter pea or hairy vetch, tillage radish, *Raphanus sativus* (L.) *var. niger* (Brassicales: Brassicaceae), and triticale, and an unplanted treatment in which plots were allowed to naturally infest with winter weeds. All soybean seed were treated with the fungicide ApronMaxx® RTA® (mefenoxam and fludioxonil, 0.0092 mg/seed, Syngenta Crop Protection, Greensboro, NC), and no insecticidal seed treatment was used.

At the V3 growth stage, soybean plots were scouted for pea leaf weevil, three cornered alfalfa hopper, and bean leaf beetle during the 2017 growing season. These three pests were not present in observable levels during the 2016 growing season. Pests were counted per meter of row for each treatment combination on the second row of each plot. Also at the V3 growth stage in 2017, a defoliation rating was estimated for each plot. After soybean plants matured, plots were mechanically harvested using a Kincaid 8XP plot combine with a weigh system and seed weights were recorded (Kincaid Equipment Manufacturing, Haven, KS). Moisture was determined and seed yields corrected to 13% and recorded for each plot.

Insect count data from the 2017 growing season were analyzed using PROC GLIMMIX of SAS® (Version 9.4, SAS Institute, Cary, NC). Previous cover type served as a fixed effect in the model. Location and replication nested in location were treated as random effects. Degrees of freedom were calculated using the Kenwood-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$). Means are presented as total number of insects per m of row of each treatment.

Insect damage data from the 2017 growing season were analyzed using PROC GLIMMIX of SAS® (Version 9.4, SAS Institute, Cary, NC). Previous cover type served as a fixed effect in the model. Location and repreplication nested in location were treated as random effects. Degrees of freedom were calculated using the Kenwood-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$). Means are presented as mean percent defoliation of each treatment.

Yield data were analyzed using PROC GLIMMIX of SAS® (Version 9.4, SAS Institute, Cary, NC). Yield data were analyzed with previous cover type as a fixed effect in the model. Siteyear and replication nested in siteyear were treated as random effects. The variable "siteyear" refers to each location of each year. Degrees of freedom were calculated using the Kenwood-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$). Means are presented as soybean yield (kg ha^{-1}).

Results

During 2016 at both locations, no observable populations of aboveground insect pests were recorded in soybean plots. Relatively low numbers of pea leaf weevil, three cornered alfalfa hopper, and bean leaf beetle were observed in the 2017 growing season. Because numbers of each pest were relatively low, the analysis was conducted on all pest species together and only in 2017. Significant differences were observed with the main effect of previous cover type in regards to mean total insects per 1 m of row at the V3 growth stage ($F = 3.05$; $df = 5, 41$; $P = 0.02$). Significantly more insect pests were observed in V3 soybean following Austrian winter pea and hairy vetch than in soybean following natural winter vegetation and winter wheat (Figure 4.1). There were no significant differences in the total number of insect pests per 1 m of row between soybean planted behind natural winter vegetation, winter wheat, the blended cover crop, or triticale.

Significant differences were observed with the main effect of previous cover type in regards to mean percent defoliation at the V3 growth stage ($F = 13.72$; $df = 5, 41$; $P < 0.01$). Significantly more defoliation at the V3 growth stage was observed in soybean following hairy vetch than in soybean behind all other previous cover types (Figure 4.2). Defoliation in V3 soybean planted behind Austrian winter pea was significantly higher than defoliation in V3 soybean planted behind natural winter vegetation, winter wheat, or triticale. Defoliation in V3 soybean did not differ between previous cover types of natural winter vegetation, the blended cover crop, winter wheat, or triticale.

Soybean harvest data were collected at all field trial locations in both growing seasons. Significant differences were observed with the main effect of previous cover type in regards to mean soybean yield ($F = 3.88$; $df = 5, 75$; $P < 0.01$). Soybean planted behind all cover crop treatments yielded significantly less than soybean planted behind natural winter vegetation (Figure 4.3).

Discussion

Winter annual cover crops can provide agronomic benefits to the crops planted behind them. Many different plant species can be used as cover crops including blends of grasses, legumes, and forbs. Understanding the influences that cover crop species have on insect pests to subsequent cash crops is important in cover crop selection and insect pest management decisions.

In the 2016 growing season, little to no aboveground insect pests were observed in the early growth stages of soybean plots planted in both locations. Relatively low numbers of pea leaf weevil, bean leaf beetle, and three cornered alfalfa hopper were observed during the early growth stages of soybean plots at both locations. The absence of large early season insect pest populations can most likely be attributed to terminating the cover crop too early before soybean planting. Cover crops were terminated four weeks prior to planting. A shorter window between the cover crops and soybean emergence would have increased the odds of having a larger infestation.

In the soybean following legume cover crops, a mean of only 4.75 insect pests per 1 m of row was observed at the V3 growth stage. These relatively low numbers did damage plants, but damage was not severe. This is clearly demonstrated when comparing defoliation with a previous study conducted in one of the same locations. Cook and Gore (2014) observed severe pea leaf weevil defoliation in soybean following a vetch cover crop in 2012. The pea leaf weevil defoliated untreated plots at a mean defoliation rating of almost 95%. Untreated soybean plots following either a hairy vetch or Austrian winter pea cover crop evaluated in our study in 2017 were defoliated at mean percentages of 41.25% and 18.75% respectively.

Damage from insect pests may have reduced yield in soybean following cover crops. Soybean planted behind each cover crop had significantly lower yields than soybean planted behind that natural winter vegetation. The soybean behind natural winter vegetation were among the previous cover types with the significantly lowest observed aboveground pests and defoliation damage at the V3 growth stage. Belowground pests may have also contributed to yield losses in the soybean following each cover crop treatment. Wireworms and white grubs are occasional belowground pests in Mid-South soybean and are influenced by tillage and the presence of grasses and other non-crop plants within fields during non-cropping months (Hesler et al. 2018). These data do show that insect pests infest Mid-South soybean at higher rates behind cover crops, specifically those that are monocultures of leguminous species. Additional studies should be conducted to examine influences of cover crops on the early season pest complex in soybean. Termination timing should be reduced to right at planting to truly understand the role cover crops may play in increasing pest problems when trying to achieve the maximum agronomic benefit.

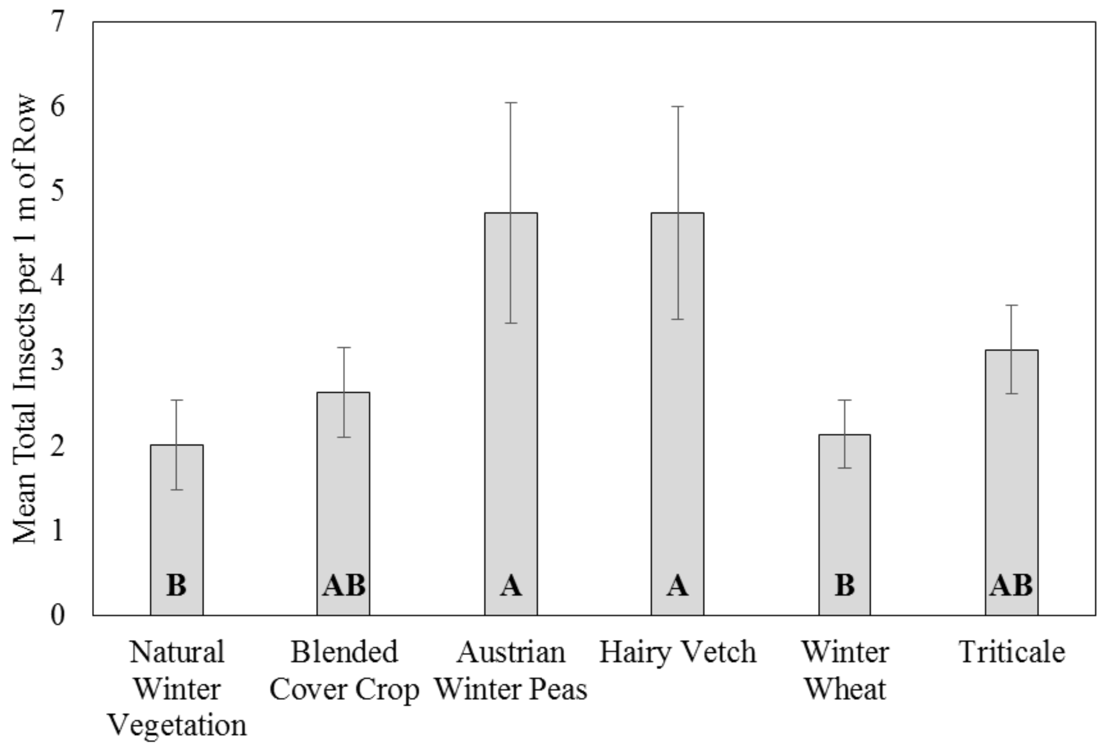

Figure 4.1 Mean total insect pests at the V3 growth stage for each previous cover type during the 2017 growing season.

Means followed by the same letter are not significantly different ($\alpha=0.05$). Error bars indicate standard error of the mean.

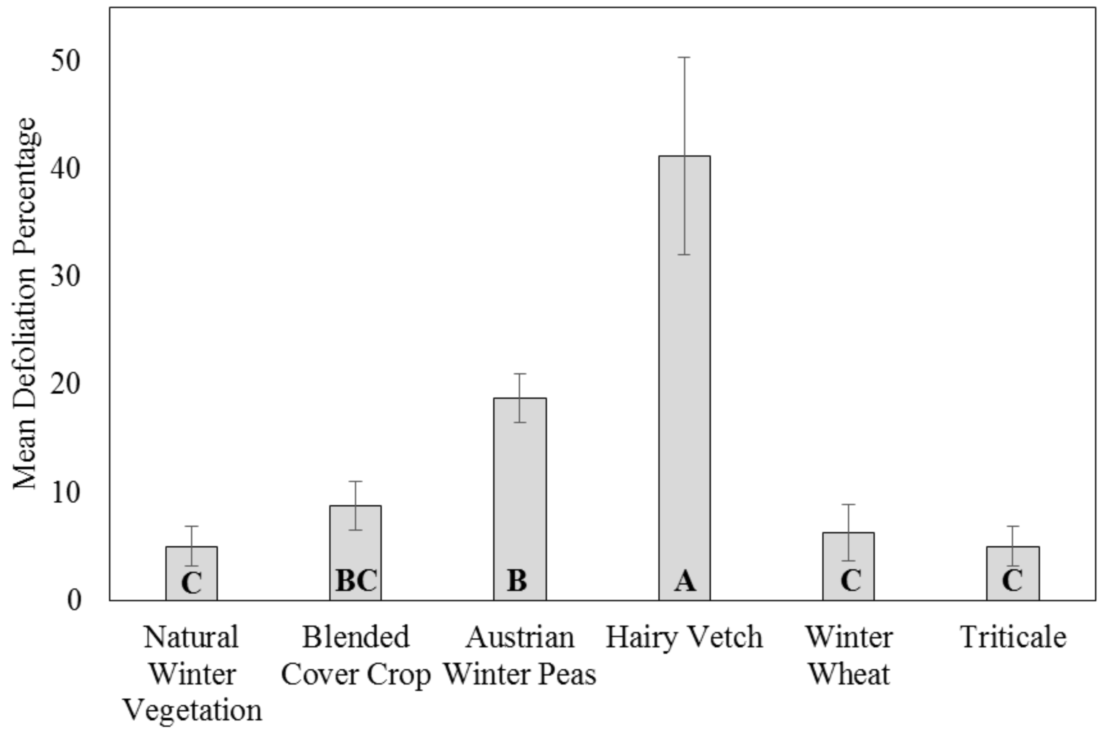

Figure 4.2 Mean percent defoliation at the V3 growth stage for each previous cover type during the 2017 growing season.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

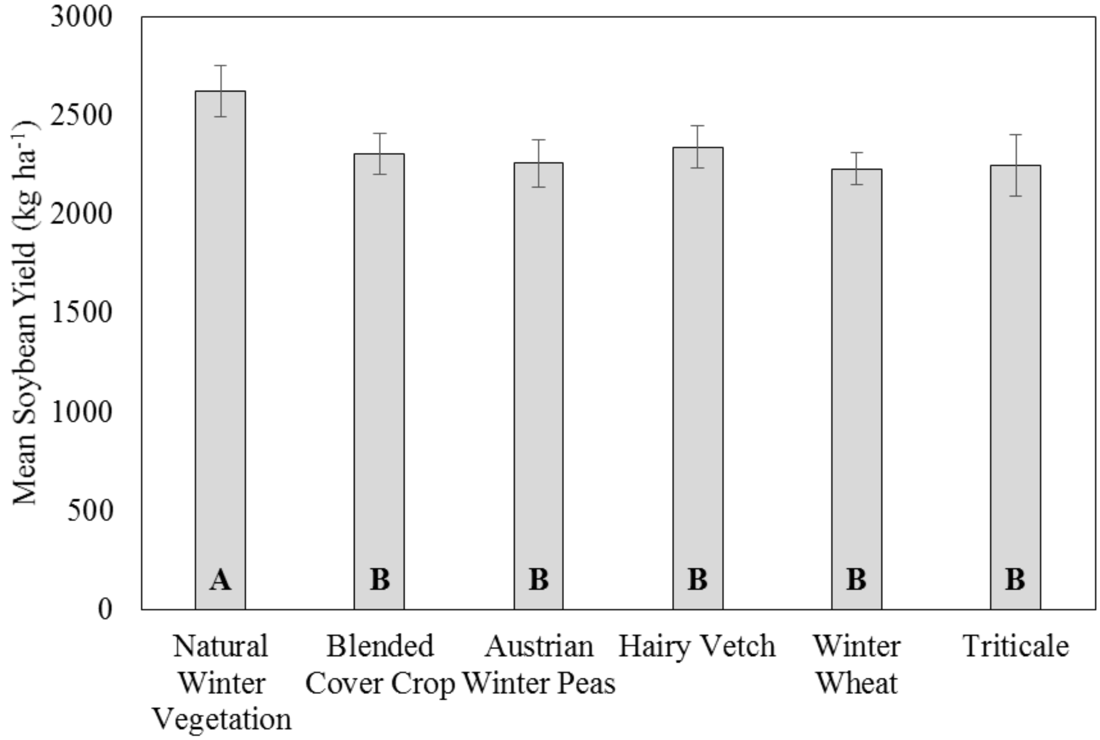

Figure 4.3 Mean soybean yield for each previous cover type.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

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CHAPTER V

IMPACTS OF WINTER ANNUAL COVER CROPS AND NEONICOTINOID SEED TREATMENTS ON ARTHROPOD DIVERSITY IN MISSISSIPPI SOYBEAN

Introduction

Winter annual cover crops are unharvested plant species that are planted into agricultural fields to achieve specific agronomic purposes (NRCS, USDA 2014). These plants occupy field space during normally barren months, providing benefits to the soil and to the cash crops planted after them (NRCS, USDA 2014). Cover crops can be made up of single species monocultures or multispecies blends. Clark (2008) lists the most commonly used cover crop species in the Mid-South agricultural region as hairy vetch, *Vicia villosa* Roth (Fabales: Fabaceae), subterranean clover, *Trifolium subterraneum* L. (Fabales: Fabaceae), berseem clover, *Trifolium alexandrinum* L. (Fabales: Fabaceae) , crimson clover, *Trifolium incarnatum* L. (Fabales: Fabaceae), annual ryegrass, *Lolium multiflorum* Lam. (Poales: Poaceae), cereal rye, *Secale cereale* L. (Poales: Poaceae), sorghum-sudangrass hybrid, *Sorghum bicolor* (L.) *x S. bicolor* (L.) *var. sudanese* (Poales: Poaceae), cowpea, *Vigna unguiculata* (L.) (Fabales: Fabaceae), sweetclover, *Melilotus officinalis* (L.) (Fabales: Fabaceae), and buckwheat, *Fagopyrum esculentum* Moench (Caryophyllales: Polygonaceae). Other popular species in the region include winter wheat, *Triticum aestivum* L. (Poales: Poaceae), triticale, *S. cereale* L. *x Triticum aestivum* L. (Poales: Poaceae), tillage radish, *Raphanus sativus* (L.) var. *niger* (Brassicales:

Brassicaceae), and Austrian winter pea, *Pisum sativum* L. subsp. *arvense* (Fabales: Fabaceae).

Grass cover crops such as cereal rye, winter wheat, and triticale are often implemented to aid in weed control, nutrient preservation, and erosion prevention (Clark 2008). Legume cover crops such as various clover species, hairy vetch, and Austrian winter pea can aid by increasing soil nitrogen, weed control, reducing erosion and soil compaction (Clark 2008). *Brassica* species such as tillage radish can also provide soil compaction benefits by providing deep root channels for later planted cash crops to follow through compacted soil (Weil and Williams 2004). The longevity of cover crop benefits can be prolonged by increasing the biomass of the cover crop. This is accomplished by planting the cover crop seed as early as possible and by delaying termination until right at planting. This is especially true when trying to suppress early season weeds (Mirsky et al. 2013, Montgomery et al. 2018). Cover crop vegetation will block sunlight from weed seed in the field preventing germination (Norsworthy et al. 2012). Termination involves killing the standing cover crop through chemical or mechanical action. Herbicides as well as roller, crimpers, and mowers can be used to kill a cover crop before planting into it (Montgomery et al. 2018, Davis 2010). When producers choose to terminate cover crops close to planting, insect pest issues can arise in the next crop (Lorenz and Goodson 2014).

The movement of insect pests from cover crop vegetation to succeeding cash crops is often attributed to a connection termed as the “Green Bridge” (Lorenz and Goodson 2014, Hodgson et al. 2015, White et al. 2015). When a sufficient host of phytophagous insects occupying the cover crop is planted behind it, these insects can cause damage to yield potential of the crop. Increasing the time between cover crop termination and the planting of the cash crop can help prevent this connection from forming. To prevent economic damage from early season insect pests, neonicotinoid seed treatments are often used in Mississippi soybean (North et al. 2016). North et al. (2016) found that over a ten year evaluation period, neonicotinoid seed treatments provided a significant yield increase when compared to seed treatments containing no insecticidal compounds. These compounds are effective to above- and below-ground pests through their systemic properties (Maienfisch et al. 2001). Neonicotinoids cause irreversible damage to arthropods that feed on early stages of crops that were treated as seed (Maienfisch et al. 2001).

The epigeal and foliar arthropod communities of soybean fields could potentially be influenced by the implementation of different winter cover crop species and neonicotinoid seed treatments. Untilled fields of dead or dying cover crops contain an organic mulch layer on top of the soil that can provide shelter and food for predatory arthropods and decomposers. Winter cover crop residues and reduced tillage practices in soybean fields have sporadically shown effects of increased arthropod diversity and increased arthropod predator activity in agricultural fields (Dunbar et al. 2017, Carmona and Landis 1999, House and Stinner 1983, House and All 1981). These organic mulch layers can vary greatly in vegetative structure and composition depending on the makeup of the cover crop species or species blend planted. An experiment was conducted with an objective to better understand how different cover crop species and neonicotinoid seed treatments affect arthropod communities in succeeding soybean fields. Soybean plots were planted behind various cover crop species. Epigeal and foliar arthropods were captured in the soybean plots with pitfall traps and sweep netting. Data from these collections were used to make ecological conclusions on whether the practices of using cover crops and neonicotinoid seed treatments affect arthropod diversity of Mississippi soybean.

Materials and Methods

Experiments were conducted in 2016 and 2017 to determine the impacts of various winter cover crops and neonicotinoid seed treatments on arthropod diversity in Mississippi soybean. The R. R. Foil Plant Science Research Center in Starkville, MS served as a location in the "Hills" region of MS located on the East side of the state, and the Mississippi State University Delta Research and Extension Center in Stoneville, MS served as a location in the "Delta" region of MS located on the West side of the state. Field trials were established on 8 row plots measuring 15.24 m long. Plots at the "Hills" location were planted on 0.97 m rows, whereas; plots at the "Delta" location were planted on 1.02 m rows. Other differences in the site locations were that the "Delta" soybean plots were irrigated, and irrigation was not possible at the "Hills" location. Two separate field trials were used for evaluating arthropod diversity in Mississippi soybean. One was used to evaluate the epigeal and foliar soybean communities when using different winter cover crop species. Another was used to evaluate the soybean epigeal community when using different soybean seed treatments and winter cover crops.

To establish the field trial plots, the cover crop treatments were planted and incorporated into the soil during the month of October before each growing season. Each cover crop seed was broadcast over plots at an even distribution. In 2016 at the "Hills" location, a drag implement was used to incorporate the cover crop seed into the soil. In 2016 in the "Delta" location and in 2017 at both locations, a roller implement was used to incorporate the cover crop seed into the soil. At approximately four weeks prior to soybean planting, a glyphosate application of 3.66 L ha^{-1} was used as a burndown application to kill the cover crops and the natural winter vegetation with and without the termination timed insecticide treatment. In addition to chemical termination, plots were rolled with an agricultural roller implement to facilitate planting in 2017 at both locations. Soybean seed, Asgrow® 4835, (Monsanto, St. Louis, MO) was planted using a tractor implemented with a John Deere® MaxEmerge® 1700 Rigid Integral 4 row wide pneumatic vacuum planter (Deere & Company, Moline, IL) during May of each growing season at a seeding rate of 271,810 plants ha^{-1} except for the increased seeding rate treatment.

The epigeal community of each field trial was sampled for arthropods using pitfall trapping. Pitfall traps were placed on row 4 of each 8 row plot. Each plot contained two pitfall traps separated by a 60.96 cm steel guide vane. The individual pitfall traps were supported by a 20.32 cm long piece of 10.16 cm diameter PVC pipe that was buried to the top so that the pipe opening was flush with the ground. A Ball® Wide Mouth Pint Glass Mason Jar (Ball Corporation, Broomfield, CO) filled approximately one-fourth of the way full with a 50/50 mixture of propylene glycol and 70% ethanol was placed into each PVC pipe. Each pitfall trap was then capped with a 10.16 cm Fisherbrand™ powder funnel (Fisher Scientific, Hampton, NH) and steel metal top. Pitfall traps were sampled at the VC and R1 growth stages of soybean development for approximately one week during each stage. The VC growth stage is when only cotyledon leaves are present on the soybean plant (Fehr et al. 1971). The R1 growth stage is when blooms first appear on the soybean plant (Fehr et al. 1971). Pitfall trapping was only conducted in 2016 in the "Hills" location and in 2017 in the "Hills" and "Delta" locations.

The foliar community of the cover crop species field trial was evaluated using sweep netting. Sweep netting was performed using a standard 38.1 cm diameter sweep net on row 5 of each plot. A total of 25 sweeps were performed and then the contents of the net were emptied into a 1 gallon plastic bag, labeled and stored in a freezer. Sweeping was performed at R1, R2, and R3 at each location. The R2 soybean growth stage is when flowers are present in the upper two nodes of the plant (Fehr et al. 1971). The R3 soybean growth stage is when a pod of 4.76 mm is present in the upper four nodes (Fehr et al. 1971). Sweep net sampling was conducted at all four siteyears.

Samples from each field trial were sorted and identified to taxonomic family. Only insect and spider specimens contributed to the data recorded; Collembola, isopods, and myriapods were not recorded. Using the family abundance data, the Shannon-Weiner index, family richness, and family evenness was calculated for each plot. The Shannon-Weiner index of each plot was then converted to the Shannon entropy (ENS) diversity index (Jost 2006).

Cover Crop Species Field Trial

The first field trial evaluated the impact of various cover crop species on arthropod diversity in soybean. Treatments were arranged in a randomized complete block design. Each randomization of treatments was replicated four times at each location. Six previous cover treatments were used that included a cover crop treatment of winter wheat, triticale, Austrian winter pea, hairy vetch, a cover crop blend of Austrian winter pea or hairy vetch, tillage radish, and triticale, or an unplanted treatment in which plots were allowed to be naturally infested with winter weeds. All soybean seed were treated with the fungicide

ApronMaxx® RTA® (mefenoxam and fludioxonil, 0.0092 mg/seed, Syngenta Crop Protection, Greensboro, NC), and no insecticidal seed treatment was used.

Diversity and family data were analyzed using analysis of variance (PROC GLIMMIX, SAS® Version 9.4, SAS Institute, Cary, NC). Separate analyses were conducted using the mean ENS and mean family richness of the epigeal community. Each were analyzed with previous cover type and soybean growth stage as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. The variable "siteyear" refers to each location of each year. Degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$).

The arthropod families, Formicidae, Lycosidae, Carabidae, and Staphylinidae, were deemed as major predatory arthropods, making up greater than 1 percent of the arthropods captured within the epigeal community. The abundances of these families were totaled for each plot and analyzed. The mean total predatory arthropod abundance was analyzed with previous cover type and soybean growth stage as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. Degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$).

The arthropod families, Chrysomelidae, Cydnidae, Membracidae, and Acrididae, and Tetrigidae, were deemed as herbivorous arthropods within the epigeal community. The abundances of these families were totaled for each plot and analyzed. The mean total herbivorous arthropod abundance was analyzed with previous cover type and soybean growth stage as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. Degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$).

The mean ENS and the mean family richness of the foliar community were independently analyzed with previous cover type and growth stage as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. The arthropod families, Carabidae, Chrysopidae, Clubionidae, Coccinellidae, Geocoridae, Nabidae, Oxyopidae, Nabidae, Pentatomidae (predatory species), Reduviidae, Salticidae, Tetragnathidae, Theridiidae, and Thomisidae were deemed as major predatory arthropods within the foliar community. The abundances of these families were totaled for each plot and analyzed. The mean total predatory arthropod abundance was analyzed with previous cover type and growth stage as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. For all analyses, degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$).

The arthropod families, Acrididae, Berytidae, Cerambycidae, Chrysomelidae, Cicadellidae, Coreidae, Curculionidae, Membracidae, Miridae, Pentatomidae (herbivorous species), Plataspidae, Tetrigidae, and Thyreocoridae were deemed as major herbivorous arthropods within the foliar community. The abundances of these families were totaled for each plot and analyzed. The mean total herbivorous arthropod abundance was analyzed with previous cover type and growth stage as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. Degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$).

Seed Treatment Field Trial

For the second field trial, treatments were arranged in a factorial arrangement within a randomized complete block design. Factor A consisted of two previous cover treatments: a cover crop blend of Austrian winter pea or hairy vetch, tillage radish, and triticale and an unplanted treatment in which plots were allowed to be naturally infested with winter weeds. Factor B consisted of two seed treatments: soybean seed treated only with the fungicide ApronMaxx® RTA® (mefenoxam and fludioxonil, 0.0092 mg/seed, Syngenta Crop Protection, Greensboro, NC) and soybean seed treated with fungicide and the neonicotinoid seed treatment CruiserMaxx® (thiamethoxam, 0.0778 mg/seed, Syngenta Crop Protection, Greensboro, NC) in 2016 and Gaucho® (imidacloprid, 0.2336 mg/seed, Bayer CropScience, Research Triangle Park, NC) in 2017.

Diversity and family data were analyzed using analysis of variance (PROC GLIMMIX, SAS® Version 9.4, SAS Institute, Cary, NC). Separate analyses were conducted using the mean ENS and mean family richness of the epigeal community. Each were analyzed with previous cover type, seed treatment, and soybean growth stage as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. The arthropod families, Formicidae, Lycosidae, Carabidae, and Staphylinidae, were deemed as major predatory arthropods within the epigeal community. The abundances of these families were totaled for each plot and analyzed. The mean total predatory arthropod abundance was analyzed with previous cover type, seed treatment, and soybean growth stage as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. For all analyses, degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$).

The arthropod families, Chrysomelidae, Cydnidae, Membracidae, Acrididae, and Tetrigidae, were deemed as major herbivorous arthropods within the epigeal community. The abundances of these families were totaled for each plot and analyzed. The mean total herbivorous arthropod abundance was analyzed with previous cover type, seed treatment, and soybean growth stage as fixed effects in the model. Siteyear and rep nested in siteyear were treated as random effects. For all analyses, degrees of freedom were calculated using the Kenward-Rogers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$).

Results

Cover Crop Species Field Trial – Epigeal Community

Epigeal arthropod data were collected for all three siteyears through the use of pitfall trapping. A significant interaction was detected between the main effects of previous cover type and soybean growth stage in regards to mean ENS ($F = 2.92$; $df = 5, 130$; $P = 0.02$). The epigeal community of soybean plots that were planted behind Austrian winter pea and sampled at the VC growth stage were significantly more diverse in regards to mean ENS than the epigeal communities of all other soybean plots planted behind the other previous cover types and sampled at both growth stages (Figure 5.1). Soybean plots planted behind hairy vetch and sampled at the VC growth stage had epigeal communities that were significantly more diverse in regards to mean ENS than those of soybean plots planted behind hairy vetch and sampled at R1, winter wheat sampled at VC, the cover crop blend sampled at R1, and the natural winter vegetation sampled at R1. The epigeal communities of soybean plots planted behind triticale sampled at both growth stages, winter wheat sampled at both growth stages, hairy vetch sampled at R1, Austrian winter pea sampled at R1, the cover crop blend sampled at both growth stages, and the natural winter vegetation sampled at VC did not significantly differ in regards to mean ENS. Soybean plots behind natural winter vegetation sampled at R1 had epigeal communities that were significantly less diverse in regards to mean ENS than those of soybean plots planted behind natural winter vegetation sampled at VC, the cover crop blend sampled at VC, Austrian winter pea at both sampled growth stages, hairy vetch sampled at VC, winter wheat sampled at R1, and triticale sampled at both growth stages.

No significant interaction existed between the main effects of previous cover type and soybean growth stage ($F = 1.24$; $df = 5, 130$; $P = 0.29$), and the main effect of previous cover type ($F = 1.84$; $df = 5, 130$; $P = 0.11$) was not significant in regards to mean family richness. Significant differences between soybean growth stages for mean family richness of the epigeal community were observed ($F = 64.87$; $df = 1, 130$; $P < 0.01$). The epigeal community of soybean plots were significantly higher in mean family richness at the VC growth stage than at the R1 growth stage (Figure 5.2).

Major families of the epigeal arthropods captured were labeled as either predators or herbivores within the soybean plots. No significant interaction existed between the main effects of previous cover type and soybean growth stage ($F = 0.85$; $df = 5, 130$; $P = 0.52$), and the main effect of previous cover type ($F = 0.32$; $df = 5, 130$; $P = 0.90$) was not significant in regards to mean total of predatory arthropods. Significant differences between soybean growth stages for mean total of predatory arthropods were observed (F = 9.07; df = 1, 130; P <0.01). Significantly more predatory arthropods were captured at the VC growth stage than at the R1 growth stage (Figure 5.3). No significant interaction existed between the main effects of previous cover type and soybean growth stage (F = 0.74; df = 5, 121; P = 0.59), and the main effect of previous cover type (F = 0.62; df = 5, 121; P = 0.69) was not significant in regards to mean total of herbivorous arthropods. Significant differences between soybean growth stages for mean total of herbivorous arthropods were observed (F = 10.90; df = 1, 121; P <0.01). Significantly more herbivorous arthropods were captured at the VC growth stage than at the R1 growth stage (Figure 5.4).

Cover Crop Species Field Trial – Foliar Community

Foliar arthropod data were collected for all four siteyears through the use of sweep netting. A significant interaction was detected between the main effects of previous cover type and growth stage in regards to mean ENS (F = 1.71; df = 15, 345; P = 0.05). The foliar communities of the hairy vetch and winter wheat cover crops were significantly more diverse in regards to mean ENS than the foliar communities of the soybean planted behind them at all growth stages (Table 5.1). All cover crop foliar communities were significantly more diverse than the natural winter vegetation in regards to mean ENS. No foliar community significantly differed among previous cover types at any soybean growth stage in regards to mean ENS.

A significant interaction was also detected between the main effects of previous cover type and growth stage in regards to mean family richness (F = 2.01; df = 15, 345; P = 0.01). All winter cover crop foliar communities, except triticale, had significantly higher mean family richness values compared to the natural winter vegetation foliar community (Table 5.2). Foliar communities of the cover crop blend and winter wheat had significantly higher family richness values than the soybean foliar communities planted behind them at the R1 and R2 growth stages. The foliar community of the hairy vetch cover crop had a significantly higher family richness than the soybean foliar communities planted behind them at all sampled growth stages. No foliar community behind any previous cover type had a significantly different mean family richness within each soybean growth stage sampled.

Major families of the foliar arthropods captured were labeled as either predators or herbivores within the soybean plots. No significant interaction existed between the main effects of previous cover type and growth stage ($F = 1.39$; $df = 15, 357$; $P = 0.15$), and the main effect of previous cover type ($F = 0.70$; $df = 5, 357$; $P = 0.62$) was not significant in regards to mean total of predatory arthropods. Significant differences between growth stages for mean total of predatory arthropods were observed ($F = 22.26$; $df = 3, 357$; $P < 0.01$). Significantly more predatory arthropods were captured in the cover crops and natural winter vegetation than in the soybean stages sampled behind them (Figure 5.5). A significant interaction between the main effects of previous cover type and growth stage sampled was observed for mean total of herbivorous arthropods ($F = 2.79$; $df = 15, 345$; $P < 0.01$). Significantly more herbivorous arthropods were found in the foliar community of cover crops containing a legume species than natural winter vegetation (Table 5.3). At the R1 and R2 growth stages, there were no significant differences among previous cover types in regards to mean herbivorous arthropod abundance within the foliar community. At the R3 growth stage, soybean behind Austrian winter pea had significantly more herbivorous arthropods within the foliar community than soybean behind hairy vetch, triticale, or natural winter vegetation. From R2 to R3, the mean abundance of herbivorous arthropods within the foliar community significantly increased in soybean following Austrian winter pea.

Seed Treatment Field Trial – Epigeal Community

Epigeal arthropod data were collected for all three siteyears through the use of pitfall trapping. No significant interaction existed between the main effects of previous cover crop, soybean growth stage, and seed treatment (F = 0.22; df = 1, 77; P = 0.64), previous cover type and soybean growth stage (F = 0.00; df = 1, 77; P = 0.99), previous cover type and seed treatment (F = 0.08; df = 1, 77; P = 0.77), or soybean growth stage and seed treatment (F = 0.51; df = 1, 77; P = 0.48) in regards to mean ENS. The main effect of previous cover type was not significant in mean ENS (F = 0.78; df = 1, 77; P = 0.38). Significant differences were observed among the main effects of seed treatment (F = 5.10; df = 1, 77; P = 0.03) or soybean growth stage (F = 8.41; df = 1, 77; P <0.01) in regards to mean ENS. The epigeal community of soybean plots were significantly more diverse in regards to mean ENS when sampled at the VC growth stage than when sampled at R1 (Figure 5.6). Soybean plots treated with a neonicotinoid seed treatment had epigeal communities with a significantly lower mean ENS than those in soybean plots not treated with the neonicotinoid seed treatment (Figure 5.7).

No significant interaction existed between the main effects of previous growth stage, soybean growth stage, and seed treatment (F = 0.07; df = 1, 86; P = 0.80), previous cover type and soybean growth stage (F = 0.01; df = 1, 86; P = 0.93), previous cover type and seed treatment (F = 0.18; df = 1, 86; P = 0.67), or soybean growth stage and seed treatment (F = 0.00; df = 1, 86; P = 1.00) in regards to mean family richness. The main effect of previous cover type was not significant in mean family richness (F = 2.62; df = 1, 86; P = 0.11). Significant differences were observed among the main effects of seed treatment (F = 9.42; df = 1, 86; P <0.01) and soybean growth (F = 44.20; df = 1, 86; P <0.01) in regards to mean family richness. The epigeal community of soybean plots were significantly more diverse in regards to mean family richness when sampled at the VC growth stage than when sampled at R1 (Figure 5.8). Soybean plots treated with a neonicotinoid seed treatment had epigeal communities with a significantly lower mean family richness than those in soybean plots not treated with the neonicotinoid seed treatment (Figure 5.9).

Major families of the foliar arthropods captured were labeled as either predators or herbivores within the soybean plots. No significant interaction existed between the main effects of previous cover type, soybean growth stage, and seed treatment (F = 0.02; df = 1, 86; P = 0.88), previous cover type and soybean growth stage (F = 0.27; df = 1, 86; P = 0.61), previous cover type and seed treatment (F = 0.00; df = 1, 86; P = 0.95), or soybean growth stage and seed treatment (F = 0.71; df = 1, 86; P = 0.40) in regards to mean total of predatory arthropods. No significant differences were observed in mean total predatory arthropods captured for the main effects of previous cover type (F = 0.20; df = 1, 86; P = 0.65), soybean growth stage (F = 0.46; df = 1, 86; P = 0.50), or seed treatment (F = 2.81; df = 1, 86; P = 0.10). There were no differences in the mean total of predatory arthropods captured between soybean plots with or without neonicotinoid seed treatments (Figure 5.10).

No significant interaction existed between the main effects of previous cover type, soybean growth stage, and seed treatment (F = 0.24; df = 1, 86; P = 0.62), previous cover type and soybean growth stage (F = 0.00; df = 1, 86; P = 0.97), previous cover type and seed treatment (F = 0.42; df = 1, 86; P = 0.52), or soybean growth stage and seed treatment (F = 0.04; df = 1, 86; P = 0.85) in regards to mean total of herbivorous arthropods. No significant differences were observed in mean total herbivorous arthropods captured for the main effects of previous cover type (F = 0.42; df = 1, 86; P = 0.52) or soybean growth stage (F = 0.90; df = 1, 86; P = 0.34). Significant differences were observed for the main effect of seed treatment in regards to mean total of herbivorous arthropods (F = 19.82; df = 1, 86; P <0.01). Significantly less herbivorous arthropods were captured in soybean plots treated with neonicotinoid seed treatments than soybean plots that were not treated with neonicotinoid seed treatments (Figure 5.11).

Discussion

Winter annual cover crops can be planted before soybean in Mississippi for many agronomic reasons. Incorporating winter annual cover crops into soybean rotations changes the seasonal hosts within fields. After the cover crops are killed, the ground structure changes and potentially affects the epigeal and foliar communities during soybean cultivation. Members of the epigeal communities in soybean fields include important predators like beetles, spiders, and ants that can attack prey on the soil surface and by climbing into the crop canopy (Kendall 2003). Some studies suggest that reducing tillage and using some species of cover crops can increase arthropod diversity and predator activity (House and Stinner 1993, Carmona and Landis 1999, Dunbar et al. 2017). Neonicotinoid seed treatments are often implemented to combat early season insect pests in soybean that follow cover crops (North et al. 2016), but the compounds are often attributed to harmful effects on the environment such as reductions in biodiversity (van der Sluijs et al. 2015). An experiment was conducted to measure the effects on the diversity of the soybean epigeal and foliar communities when incorporating cover crops as well as insecticidal seed treatments into Mississippi soybean growing systems.

Cover Crop Species Field Trial

Soybean plots behind the leguminous cover crops, Austrian winter pea and hairy vetch, supported epigeal communities that were more diverse at the earlier growth stage than other soybean plots behind different cover types at the two growth stages. Soybean epigeal communities behind Austrian winter pea were the most diverse at VC but quickly leveled out to the same mean ENS diversity levels of soybean epigeal communities behind winter wheat and triticale. The mulch of this legume species was the most attractive to epigeal arthropods at the earliest stage. Austrian winter peas can hosts many phytophagous insects, and a carry-over effect could have influenced the arthropod community during the early growth stages of soybean. As terminated cover crops desiccate and decompose, the diversity of most of the soybean epigeal communities decreased in terms of mean ENS, family richness, predator abundance, and herbivore abundance. Epigeal arthropods can utilize the mulch formed by the decaying cover crops as shelter, and detritivores can feed on the decomposing vegetation. Soybean behind cover crops comprised of a single grass species lost no diversity in regards to mean ENS from the VC growth stage to the R1 growth stage. Grass species grow vertically; whereas, legume species grow more horizontally in vining masses. This vertical growth could have provided a longer lasting mulch that did not decay as rapidly as the cover types containing non-grass species.

Foliar communities in the hairy vetch and winter wheat cover crops were significantly more diverse in mean ENS than the soybean plots planted behind them. The cover crop foliar communities were significantly more diverse than the natural winter vegetation foliar community in mean ENS and mean family richness. After soybean plots reached reproductive growth stages, previous cover types did not affect the diversity of the foliar community. The long amount of time between cover crop destruction and the reproductive stages of the soybean plots planted behind them could have prevented foliar arthropods from persisting within those plots the entire time.

Seed Treatment Field Trial

The epigeal community of soybean sampled at the VC growth stage had a significantly higher mean ENS and a significantly higher mean family richness than the epigeal community of soybean sampled at the R1 growth stage. Also, the epigeal community of soybean treated with only a fungicide seed treatment had a significantly higher mean ENS and a significantly higher mean family richness than the epigeal community of soybean treated with both a fungicide and neonicotinoid seed treatment. At the VC growth stage, more decaying vegetation is present for arthropods to utilize as both shelter and food which would cause the increased mean ENS and family richness. Neonicotinoid seed treatments applied to seed coatings are absorbed into plant tissue and kill insects feeding on the seedling plants. These decreases in mean ENS and mean family richness are most likely due to decreases in insect herbivores. No differences were observed in the total number of predatory arthropods among previous cover types, growth stages sampled, or seed treatments. Therefore, while neonicotinoid seed treatments did decrease diversity, this reduction was only due to decreases in arthropods that fed on the treated soybean plants. Predatory arthropods of the epigeal community were not reduced by the neonicotinoid compounds.

Conclusions

Legume cover crops had significant impacts on the epigeal community diversity of soybean planted behind them. These cover crops, especially hairy vetch, supported a more diverse foliar community before termination. To prevent increases in herbivorous arthropods, neonicotinoid seed treatments can be used without affecting epigeal predators such as beetles, ants, and spiders. The neonicotinoid seed treatments can affect diversity, but the reductions will be caused by decreases in insects feeding on treated soybean plants.

Table 5.1 Mean Shannon Entropy Index (ENS) of foliar communities for the interaction between growth stages and previous cover types.

Soybean Growth Stage	**Previous Cover Type**	**Mean ENS**	**SEM**
Before Cover Crop Termination	Natural Winter Vegetation	2.52de	0.19
	Blended Cover Crop	3.84a	0.34
	Austrian Winter Peas	3.34ab	0.37
	Hairy Vetch	3.81a	0.26
	Winter Wheat	3.84a	0.25
	Triticale	3.31ab	0.22
R1	Natural Winter Vegetation	2.66bcde	0.24
	Blended Cover Crop	2.80bcde	0.13
	Austrian Winter Peas	2.88bcde	0.24
	Hairy Vetch	2.52de	0.18
	Winter Wheat	2.50e	0.19
	Triticale	2.31e	0.15
R2	Natural Winter Vegetation	2.75bcde	0.30
	Blended Cover Crop	2.58cde	0.22
	Austrian Winter Peas	2.74bcde	0.30
	Hairy Vetch	2.69bcde	0.23
	Winter Wheat	2.70bcde	0.20
	Triticale	2.80bcde	0.27
R3	Natural Winter Vegetation	3.20abcd	0.38
	Blended Cover Crop	3.23abc	0.35
	Austrian Winter Peas	2.66bcde	0.26
	Hairy Vetch	2.87bcde	0.30
	Winter Wheat	2.72bcde	0.24
	Triticale	2.69bcde	0.31

Means followed by the same letter are not significantly different at ($P \leq 0.05$).

Table 5.2 Mean family richness of foliar communities for the interaction between growth stages and previous cover types from the Cover Crop Species Field Trial.

Soybean Growth Stage	**Previous Cover Type**	**Mean Family Richness**	**SEM**
Before Cover Crop Termination	Natural Winter Vegetation	2.94h	0.19
	Blended Cover Crop	4.81ab	0.39
	Austrian Winter Peas	4.31bcde	0.51
	Hairy Vetch	5.38a	0.41
	Winter Wheat	4.75abc	0.31
	Triticale	3.81defgh	0.23
R1	Natural Winter Vegetation	3.38fgh	0.29
	Blended Cover Crop	3.63defgh	0.15
	Austrian Winter Peas	3.69defgh	0.24
	Hairy Vetch	3.44efgh	0.24
	Winter Wheat	3.19gh	0.21
	Triticale	2.94h	0.23
R2	Natural Winter Vegetation	3.69defgh	0.52
	Blended Cover Crop	3.31fgh	0.34
	Austrian Winter Peas	3.63defgh	0.40
	Hairy Vetch	3.63defgh	0.35
	Winter Wheat	3.69defgh	0.30
	Triticale	3.75defgh	0.42
R3	Natural Winter Vegetation	4.19bcdef	0.61
	Blended Cover Crop	4.44bcd	0.56
	Austrian Winter Peas	4.13bcdef	0.57
	Hairy Vetch	4.00bcdefg	0.49
	Winter Wheat	3.94bcdefg	0.47
	Triticale	3.88cdefg	0.56

Means followed by the same letter are not significantly different at ($P \leq 0.05$).

Table 5.3 Mean total of herbivorous arthropods of foliar communities for the interaction between growth stages and previous cover types from the Cover Crop Species Field Trial.

Soybean Growth Stage	**Previous Cover Type**	**Mean Total of Herbivorous Arthropods**	**SEM**
Before Cover Crop Termination	Natural Winter Vegetation	5.50d	1.20
	Blended Cover Crop	11.50bc	2.06
	Austrian Winter Peas	11.25bc	2.31
	Hairy Vetch	18.50a	2.93
	Winter Wheat	7.94cd	1.54
	Triticale	5.13d	0.99
R1	Natural Winter Vegetation	8.31cd	1.09
	Blended Cover Crop	10.38c	2.18
	Austrian Winter Peas	11.31bc	1.38
	Hairy Vetch	9.25cd	1.27
	Winter Wheat	11.19bc	1.98
	Triticale	7.50cd	1.52
R2	Natural Winter Vegetation	8.38cd	1.75
	Blended Cover Crop	8.44cd	1.49
	Austrian Winter Peas	8.19cd	1.74
	Hairy Vetch	8.00cd	1.09
	Winter Wheat	8.31cd	1.22
	Triticale	8.88cd	1.61
R3	Natural Winter Vegetation	9.44cd	2.15
	Blended Cover Crop	11.50bc	2.32
	Austrian Winter Peas	14.94ab	5.00
	Hairy Vetch	9.06cd	1.85
	Winter Wheat	11.69bc	2.62
	Triticale	10.25c	2.17

Means followed by the same letter are not significantly different at ($P \leq 0.05$).

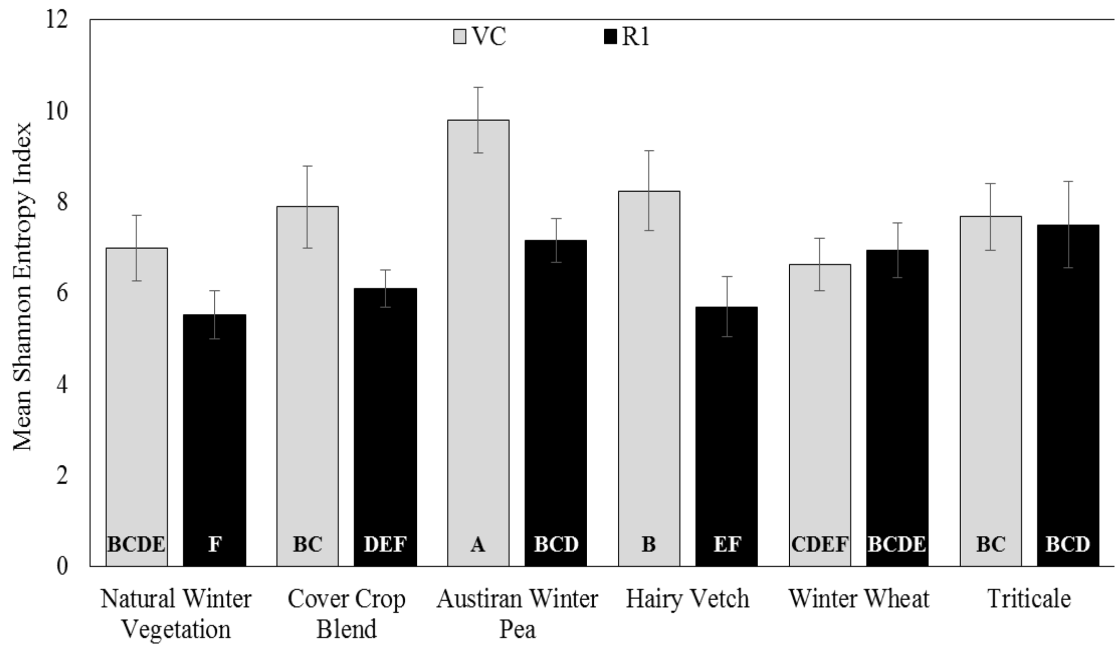

Figure 5.1 Mean Shannon Entropy Index (ENS) of epigeal communities for the interaction between growth stages and previous cover types from the Cover Crop Species Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

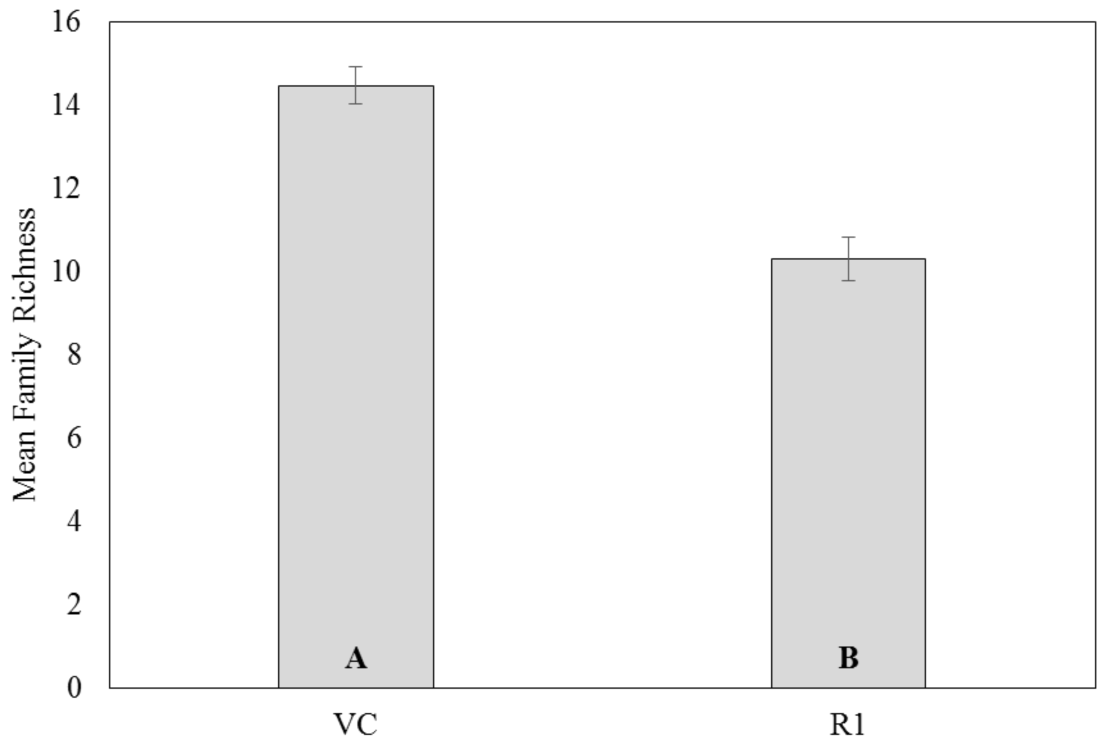

Figure 5.2 Mean family richness of the epigeal communities at the different soybean growth stages sampled in the Cover Crop Species Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

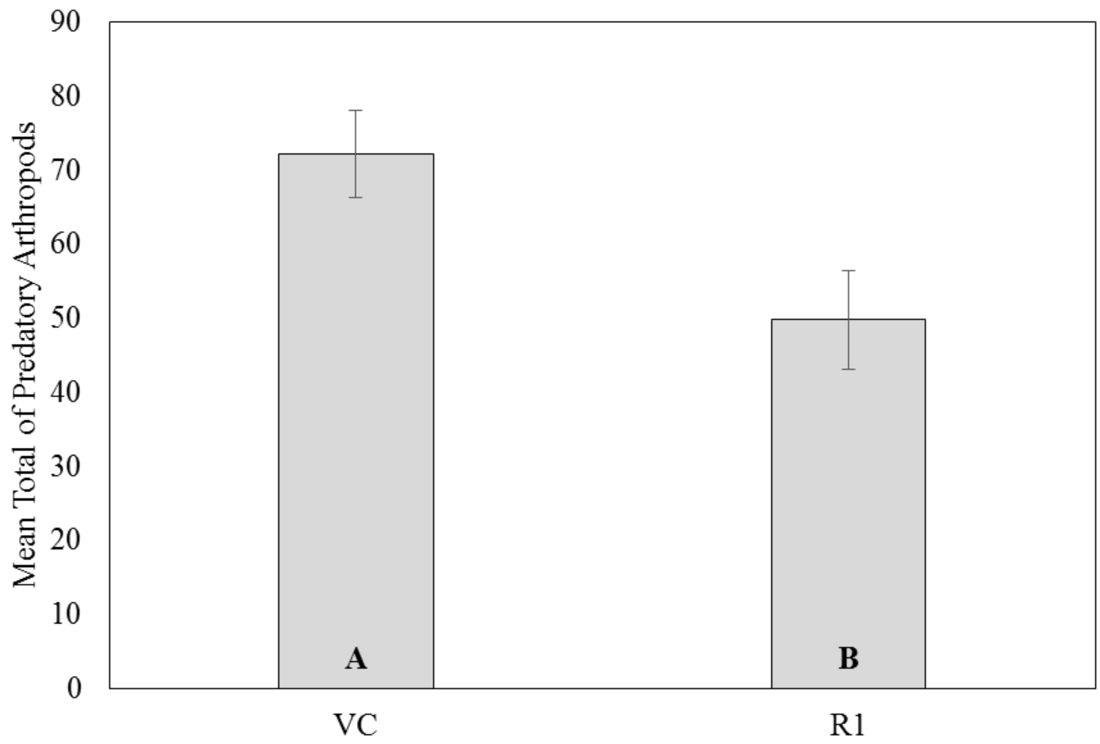

Figure 5.3 Mean total of predatory arthropods within epigeal communities at the different soybean growth stages sampled in the Cover Crop Species Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

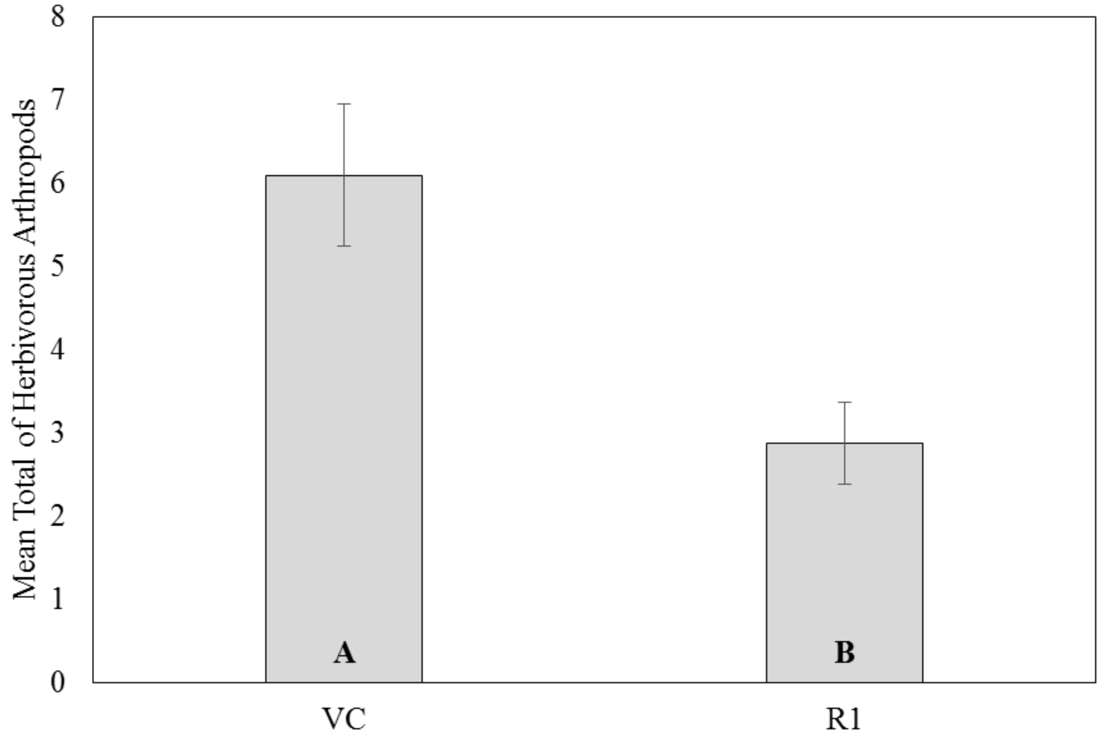

Figure 5.4 Mean total of herbivorous arthropods within epigeal communities at the different soybean growth stages sampled in the Cover Crop Species Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

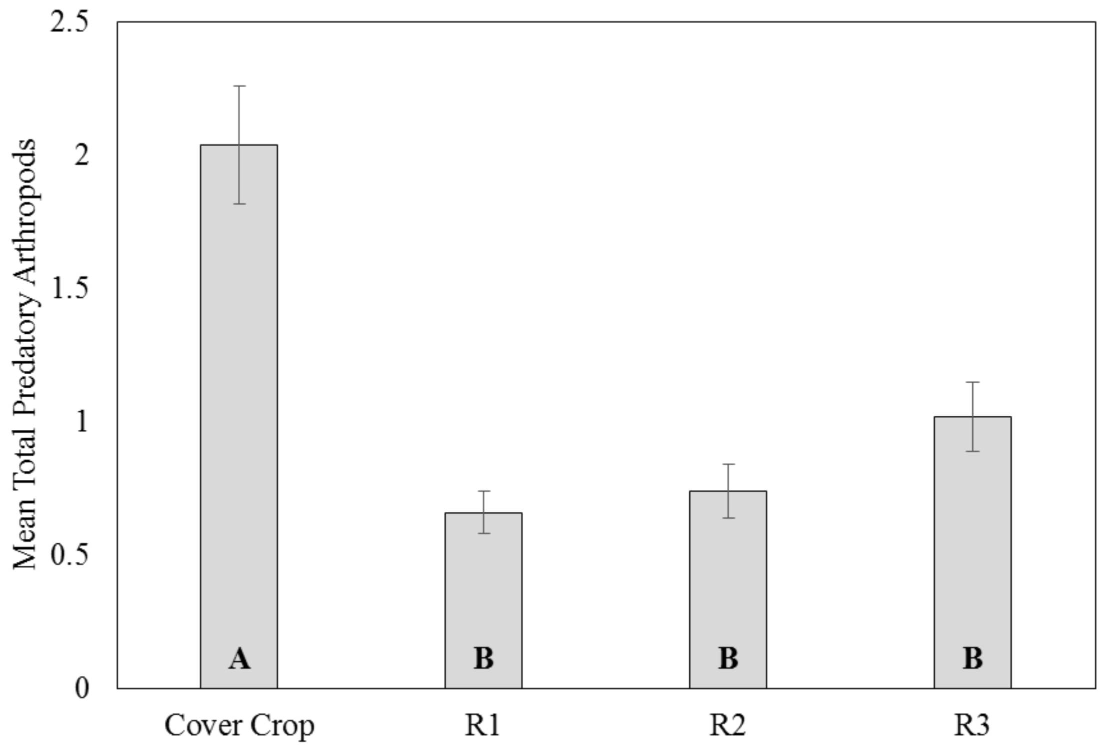

Figure 5.5 Mean total of predatory arthropods of the foliar communities at the different soybean growth stages sampled in the Cover Crop Species Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

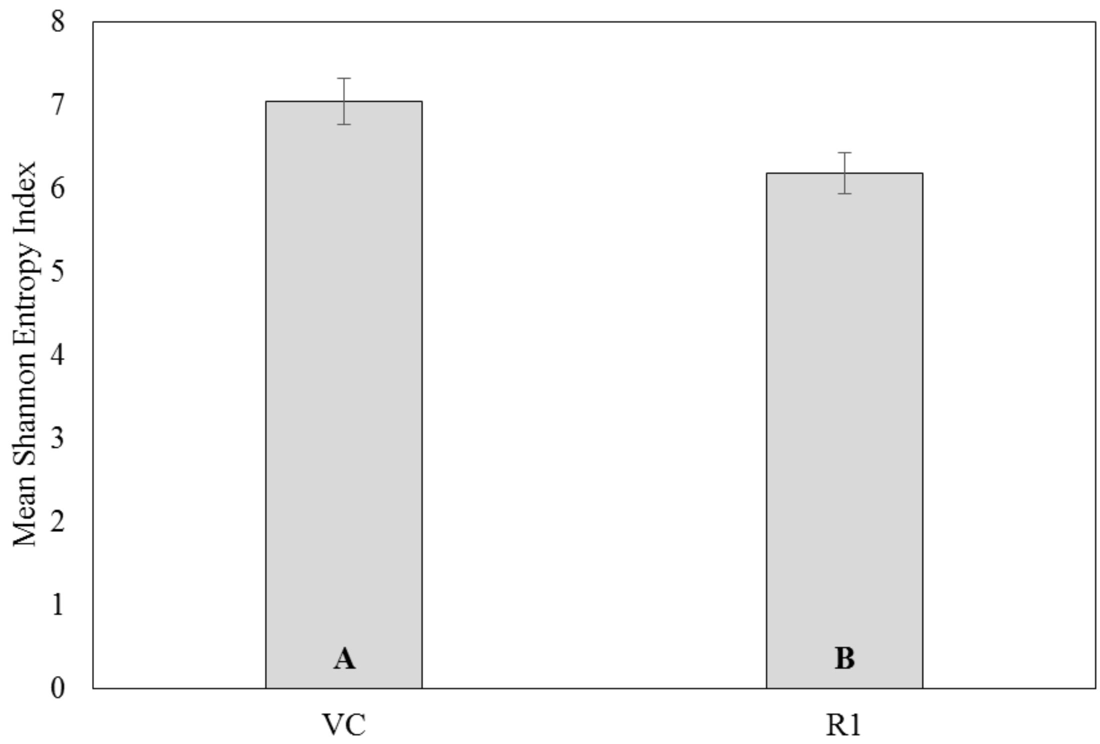

Figure 5.6 Mean Shannon Entropy Index (ENS) of the epigeal communities at the different soybean growth stages sampled in the Seed Treatment Field Trial.

Means followed by the same letter are not significantly different ($\alpha=0.05$). Error bars indicate standard error of the mean.

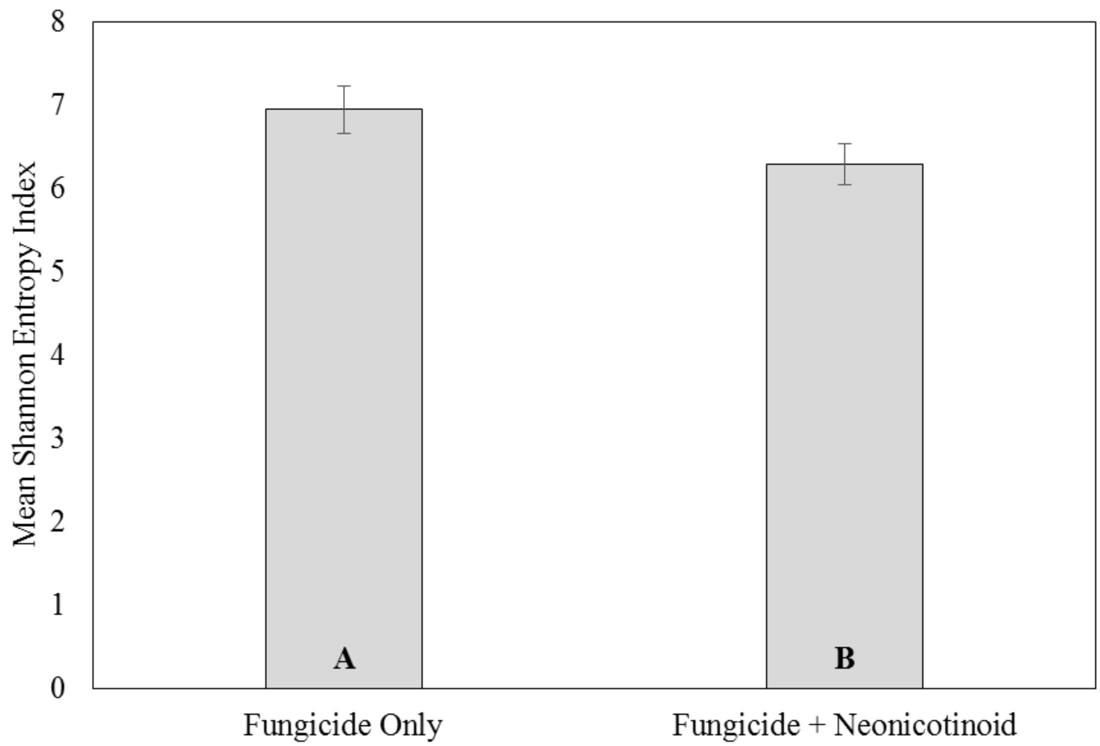

Figure 5.7 Mean Shannon Entropy Index (ENS) of the epigeal communities of plots treated with different seed treatments in the Seed Treatment Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

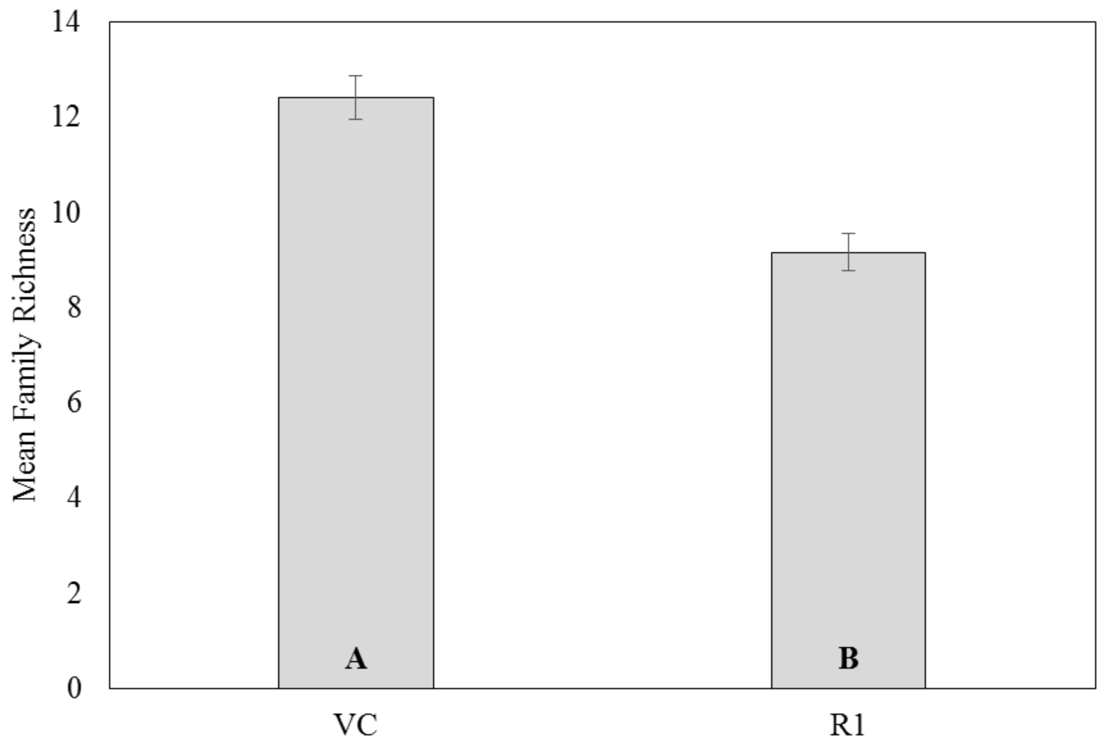

Figure 5.8 Mean family richness of the epigeal communities at the different soybean growth stages sampled in the Seed Treatment Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

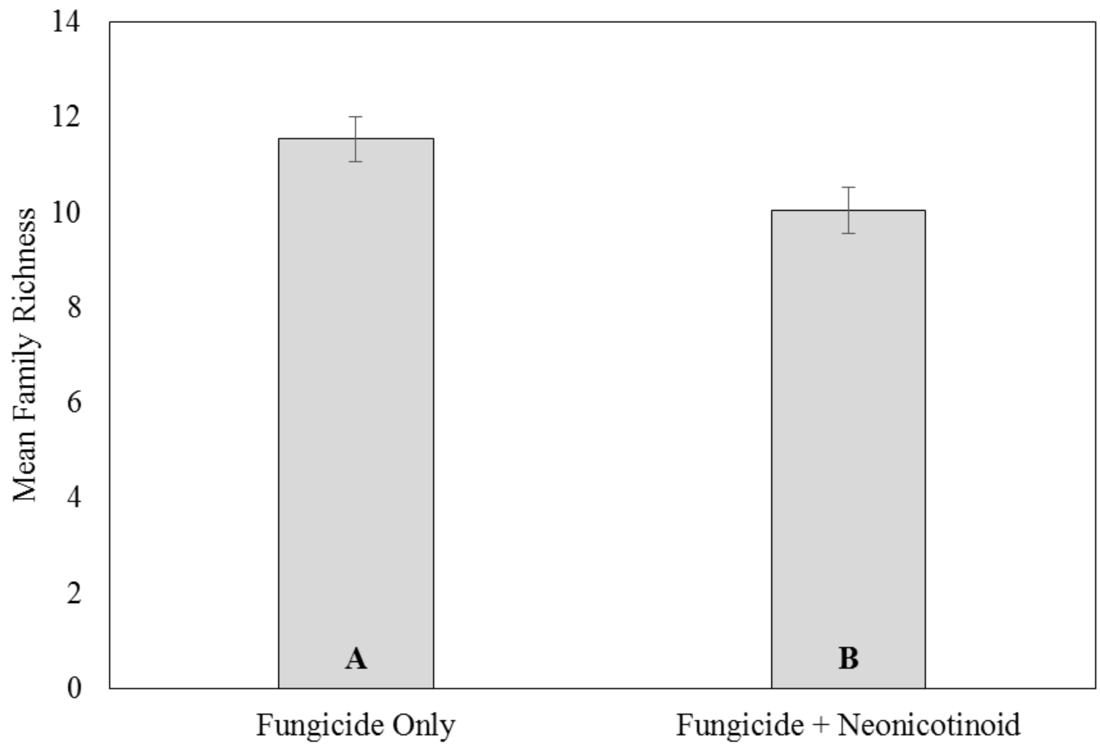

Figure 5.9 Mean family richness of the epigeal communities of plots treated with different seed treatments in the Seed Treatment Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

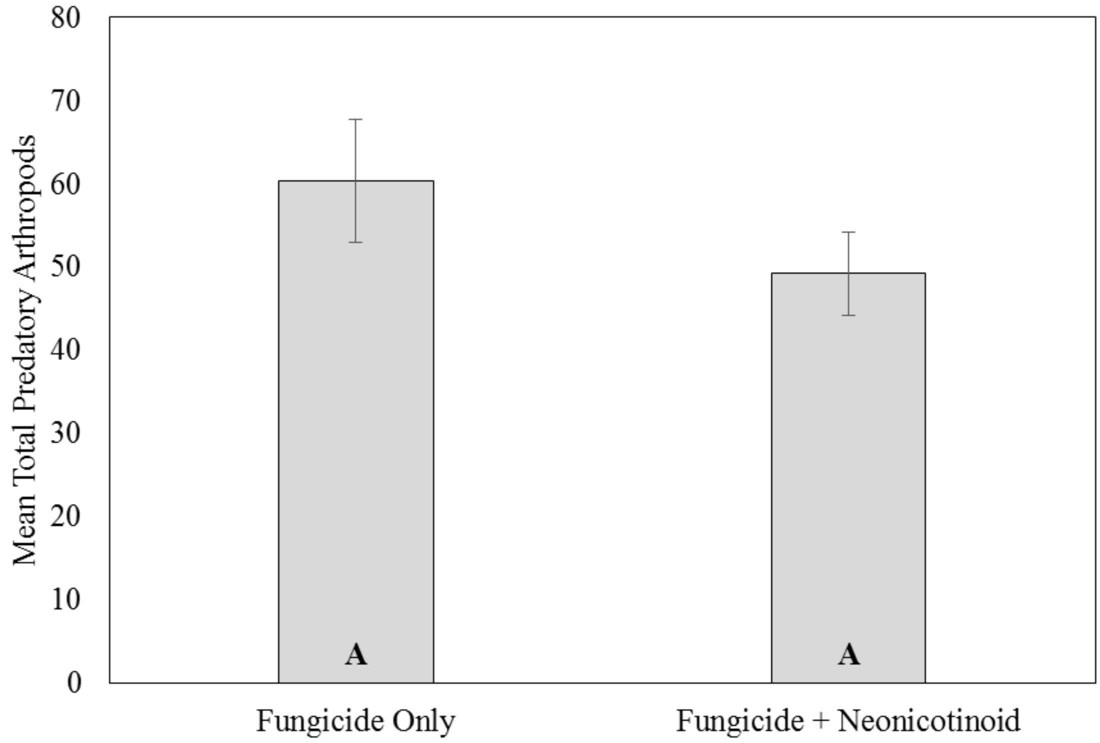

Figure 5.10 Mean total of predatory arthropods in the epigeal communities of plots treated with different seed treatments in the Seed Treatment Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

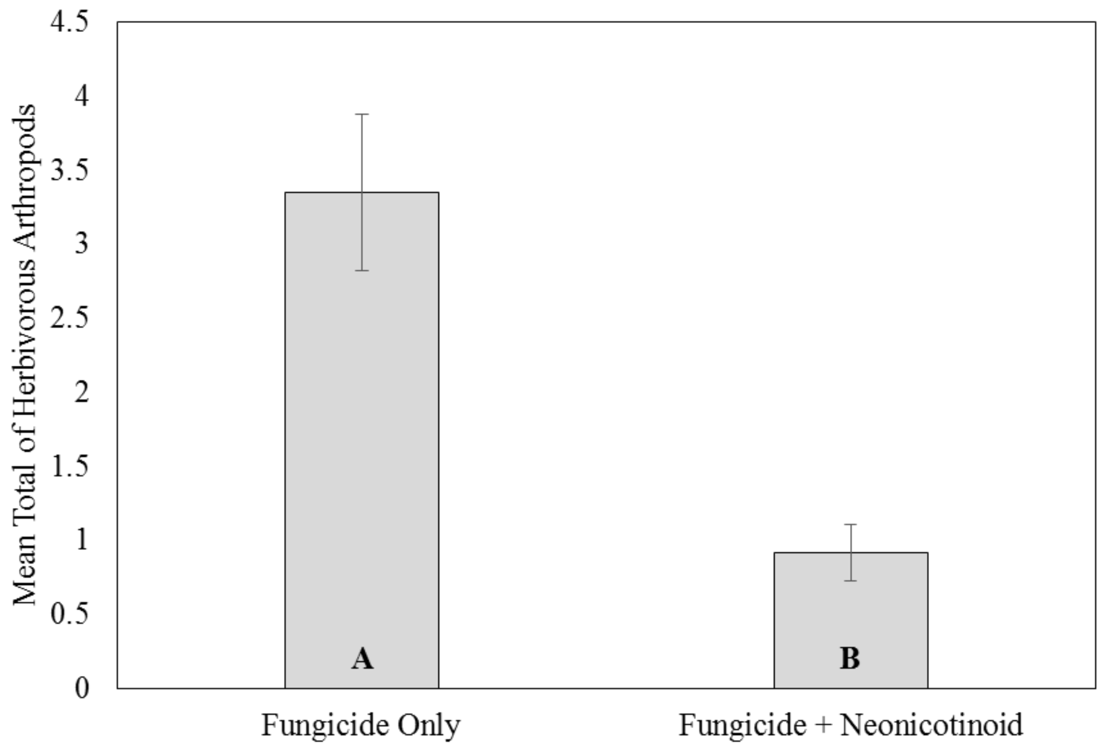

Figure 5.11 Mean total of herbivorous arthropods in the epigeal communities of plots treated with different seed treatments in the Seed Treatment Field Trial.

Means followed by the same letter are not significantly different (α=0.05). Error bars indicate standard error of the mean.

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APPENDIX A

SUPPLEMENTAL DATA FOR CHAPTER V

Table A.1 Total and Percentage of the Total Catch for each Family Captured within the Epigeal Community in the Cover Crop Species Field Trial

Family	Total of Individuals	% of Total Catch	Family	Total of Individuals	% of Total Catch
Formicidae	3997	27.56	Membracidae	30	0.21
Lycosidae	2757	19.01	Corylophidae	23	0.16
Gryllidae	1228	8.47	Mycetophagidae	19	0.13
Staphylinidae	1015	7.00	Reduviidae	15	0.10
Carabidae	1008	6.95	Geocoridae	14	0.10
Linyphiidae	860	5.93	Theridiidae	12	0.08
Anthicidae	611	4.21	Cicadellidae	9	0.06
Phoridae	595	4.10	Coccinelidae	7	0.05
Latridiidae	308	2.12	Pentatomidae	5	0.03
Cydnidae	270	1.86	Miridae	4	0.03
Elateridae	235	1.62	Anthocoridae	4	0.03
Acrididae	232	1.60	Stratiomyidae	4	0.03
Sciaridae	199	1.37	Coreidae	3	0.02
Nitidulidae	158	1.09	Dolichopodidae	3	0.02
Anisolabididae	158	1.09	Sarcophagidae	3	0.02
Curculionidae	138	0.95	Chrysopidae	3	0.02
Scarabaeidae	130	0.90	Platystomatidae	2	0.01
Platygastridae	78	0.54	Byrrhidae	1	0.01
Noctuidae	74	0.51	Rhyparochromidae	1	0.01
Ulidiidae	70	0.48	Tridactylidae	1	0.01
Blissidae	61	0.42	Tipulidae	1	0.01
Tetrigidae	59	0.41	Mutillidae	1	0.01
Chrysomelidae	55	0.38			
Pompilidae	43	0.30			

Table A.2 Total and Percentage of the Total Catch for each Family Captured within the Foliar Community in the Cover Crop Species Field Trial

Family	Total of Individuals	% of Total Catch
Membracidae	1993	43.20
Miridae	621	13.46
Chrysomelidae	463	10.04
Acrididae	352	7.63
Coccinellidae	167	3.62
Cicadellidae	88	1.91
Pentatomidae	71	1.54
Tetrigidae	62	1.34
Geocoridae	61	1.32
Oxyopidae	58	1.26
Curculionidae	51	1.11
Reduviidae	29	0.63
Thyreocoridae	26	0.56
Nabidae	23	0.50
Plataspidae	22	0.48
Theridiidae	21	0.46
Carabidae	17	0.37
Coreidae	12	0.26
Tetragnathidae	11	0.24
Chrysopidae	10	0.22
Salticidae	7	0.15
Cerambycidae	7	0.15
Thomisidae	6	0.13
Clubionidae	5	0.11
Berytidae	2	0.04

Table A.3 Total and Percentage of the Total Catch for each Family Captured within the Epigeal Community in the Seed Treatment Field Trial

Family	**Total of Individuals**	**% of Total Catch**	**Family**	**Total of Individuals**	**% of Total Catch**
Formicidae	2662	33.11	Pompilidae	25	0.31
Lycosidae	1598	19.87	Chrysomelidae	23	0.29
Gryllidae	676	8.41	Platygastridae	22	0.27
Carabidae	524	6.52	Membracidae	12	0.15
Staphylinidae	478	5.94	Corylophidae	10	0.12
Linyphiidae	455	5.66	Geocoridae	7	0.09
Anthicidae	424	5.27	Mycetophagidae	5	0.06
Phoridae	332	4.13	Reduviidae	5	0.06
Latridiidae	122	1.52	Tetrigidae	4	0.05
Nitidulidae	97	1.21	Cicadellidae	3	0.04
Sciaridae	92	1.14	Theridiidae	3	0.04
Acrididae	85	1.06	Pentatomidae	2	0.02
Cydnidae	81	1.01	Coccinelidae	1	0.01
Elateridae	62	0.77	Byrrhidae	1	0.01
Ulidiidae	56	0.70	Miridae	1	0.01
Curculionidae	54	0.67	Anthocoridae	1	0.01
Anisolabididae	53	0.66	Coreidae	1	0.01
Scarabaeidae	35	0.44	Ichneumonidae	1	0.01
Blissidae	28	0.35	Noctuidae	1	0.01