

**Influence of Traditional and Dual-Use Cropping on Arthropods and
Slugs in Soybean in Tennessee**

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Dedication

To
Charles Lee Longmire
and
Sandra Gail Longmire
my parents

Thank you for the constant love and support throughout my life and for raising me to be the person that I am. I would have never made it this far without you.

And to

Edna Ruth Tudor

My grandmother who always believed in me. Thank you for always encouraging my love for bugs, even though you didn't always want to be around them like I did.

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Abstract

Soybean is the number one agricultural crop in Tennessee for both number of hectares planted and economic value. Soybean, used in various products, is marketed globally. In recent years, Tennessee soybean growers have shown an increased interest in the use of cover crops with soybean. A cover crop is planted before the cash crop and can minimize some weeds, diseases, insects, and other pests. Traditionally, cover crops are terminated in the spring before cash crop planting. Traditional methods of cover cropping provide many benefits but can also produce some undesired results. Dual-use cover cropping is a newer method of cover cropping in which dual-purpose cover crops are harvested as a forage crop prior to planting the cash crop. Unfortunately, little research has investigated the impact of dual-use cropping on populations of insects and other arthropods, as well as slugs, in Tennessee.

A two-year study designed to evaluate the impact of dual-use cover cropping on pest and beneficial arthropods and slugs was initiated in east and middle Tennessee by using a five cover crop treatments and two management practices in soybean. The primary research goals of this project were to: 1) evaluate impact of dual-use cover cropping on pest and beneficial arthropods, 2) assess influence of dual-use cover cropping on density and impact of slugs, and 3) determine influence of dual-use cover cropping and pests on soybean yield. The results of this study have shown that management practice (i.e., traditional or dual-crop) did not have a significant ($p \geq 0.05$) effect on overall arthropod or slug densities. However, significant ($p < 0.05$) differences were found between some of the cover crop treatments and arthropod densities. Management practice and cover crop treatment did not result in an increase in pest problems in soybean. Cover crop treatment and management practice also did not significantly ($p \geq 0.05$) impact soybean yield. Findings from this research should enable soybean growers to better understand

cover crop-arthropod interactions to enhance soybean production in Tennessee. Further research on impact of plot sizes and insecticide seed treatment on insects and slugs may better define results and increase use of dual-cropped soybean.

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CHAPTER I

Introduction/Literature Review

Introduction

The industry of agriculture produces food for countless individuals on a global basis, and plays a critical role in keeping people fed in most countries, including the United States. In the 1930s, one farmer only had to grow enough food for about four people (Kirschenmann 2001). According to the 2017 Census of Agriculture, an average United States farm now provides food for 166 people annually in the United States and abroad (AFBF 2020). With so few farmers producing food for such a large number of people, precise and effective farming techniques are becoming more and more important. The global population is expected to increase by 2.2 billion by 2050, which would mean that farmers in the United States and abroad would have to produce about 70% more food than what is currently being grown (AFBF 2020). High yielding crops with minimal losses will become increasingly more crucial as populations rise.

Insects have an enormous impact on the agricultural industry. Some insects can help to increase yields through pollination or predation of other pests. However, other insects can be detrimental to agricultural systems. An agricultural pest is defined as an “animal or plant whose population density exceeds some unacceptable threshold level, resulting in economic damage” (Horn 1988). By that definition, it comes as no surprise that many insects are considered to be pests of agriculture. Even with the widespread use of pest management tactics, Pimentel and co-workers (2005) estimated that insect pests annually damage about 13% of potential crop production representing a value of about \$33 billion in the United States. Additionally, non-native invasive species, species that have expanded outside their native range and are considered to be pests, account for around 40% of agricultural insect pest species (Pimentel et al. 2005). On

a global scale, herbivorous insects are annually responsible for destroying nearly one fifth of the world's total crop production (Sallam et al. 2013). The introduction of new invasive species has become much more of a common and frequent occurrence because of increases in global trade and travel, and it is unlikely that the rate of new introductions will slow down any time soon (Pimentel et al. 2005).

Growers generally select crops based on high yields and nutritious value (Sallam et al. 2013). Because farms have a limited area, crops are typically clustered in a confined area. These conditions provide the right conditions not only for agricultural production, but also provide a highly conducive environment for insect pests (Sallam et al. 2013). Humans artificially select for specific desired traits for crops. In an effort to produce crops that meet consumer demand, growers may exacerbate the conditions that are highly susceptible for insect infestations.

Chemical pesticides are commonly and widely used as a primary method of control against insect pests. However, several issues are associated with the use of pesticides. One issue is that they can be costly. Every year, about 3 billion kg (active ingredients) of pesticides are applied worldwide with a cost of nearly \$40 billion (Pimentel and Burgess 2014). In the United States alone, approximately 500 million kg (active ingredients) of more than 600 different types of pesticide are applied annually at a cost of \$10 billion (Pimentel et al. 2005). Another issue is that pesticide use does not always decrease crop losses. Despite a more than 10-fold increase in the use of insecticide in the United States from 1945 to 2000, Pimentel and Burgess (2014) estimated that total crop losses resulting from insect damage have nearly doubled from 7% to 13%. This increase is, in part, due to the fact that insects are capable of quickly adapting to new environmental stresses and conditions (Sallam et al. 2013). Because of their adaptability, insects

can develop resistance to pesticides making them less effective or completely ineffective at controlling pests (Sallam et al. 2013).

Pesticides can also have an impact on non-target, beneficial insects (Fernandes et al. 2016). Even if these beneficial insects are not directly killed by contact with a pesticide, they can still be affected. For example, a predatory species, such as *Orius insidiosus* (Say), may consume the target pest of an insecticide treatment who has ingested the insecticide and kill the predator as a result. Synthetic chemical pesticides have been used widely during the last 80 years, and their use will continue to play a vital role in pest management. However, they are a short-term solution because they may have to be applied several times during the growing season and usually must be applied every growing season. Thus, applications must continue to remain effective. As agricultural production expands and becomes increasingly important, more long-term, ecological and sustainable solutions will also be needed to combat these pests.

Soybean

Soybean, *Glycine max* (L.) Merr., is a legume believed to have been first cultivated in China during the 11th century B.C. (Qiu and Chang 2010, University of Nebraska 2018). China was the world's leading producer and exporter of soybean for the first half of the 20th century, however, by the early 21st century, they ranked fourth after the United States, Brazil, and Argentina (Qiu and Chang 2010). To meet their own demands, China is now the largest importer of soybean. Soybean was first introduced to the United States in 1765 by a colonist in Georgia (North Carolina Soybean Producers Association 2014a). However, it was not until the 1870s that soybean became popular with American farmers as a forage crop to feed livestock.

Soybean is now the second-most-planted field crop in the United States after corn (USDA ERS 2017). The majority of soybean in the United States is grown in the Midwest,

however, amounts are grown in several southeastern states, including Tennessee, where it is the number one agricultural crop in terms of both number of hectares planted and in economic value (Smith 2017, USDA/NASS 2018). In 2017, 3.36 metric tons of soybean were harvested per hectare across almost 688,000 harvested hectares in Tennessee. The estimated value of this crop was \$680.3 million for 2017. In 2019, soybean persisted as an important crop with 3.16 metric tons harvested per hectare across approximately 554,400 hectares (UT Crops 2020). Soybean has a variety of uses and is marketed globally. Soybean is used in feeds, food, vegetable oil, biofuel, plastics, and even in inks and crayons (North Carolina Soybean Producers Association 2014b). Because soybean is such an important crop, particularly in Tennessee, it is imperative that farmers have all the information available to protect their investment. Using sound and effective pest management strategies is a good way to ensure this protection.

Cover Crops

One method that many farmers are implementing to enhance their soybean system is cover cropping. A cover crop is a crop that is planted before the cash crop primarily in an effort to manage soil erosion, soil fertility, soil quality, biodiversity, and wildlife in an agricultural system (Gesch et al. 2014). In some cases, cover cropping can help to enhance growers' profits through programs that will sometimes pay subsidies for using cover crops, such as the Natural Resources Conservation Service's Environmental Quality Incentives Program (EQIP). Cover cropping can also be used to minimize the number of weeds, diseases, insects, and other pests that impact the cash crop (Clark 2008, McClure et al. 2017). However, there is not much research on cover crop – pest interactions. Cover cropping also adds new plant species into the system, which can change plant and animal compositions and increase biodiversity (Schipanski et al. 2014). Some cover crops can increase beneficials, such as pollinators and predatory insects

(Bugg and Waddington 1994, Clark 2008, Eberle et al. 2015, Schipanski et al. 2014). Cover crops can also aid in reducing the need for fertilizers and pesticides (Schipanski et al. 2014, Snapp et al. 2005). This reduction in fertilizer and pesticide use could potentially mean that cover cropping could become more of a cost effective and long-term solution for pest management than solely relying on pesticides for control.

For annual cash crops, cover crops are typically grown through the winter and usually terminated in the spring before planting the cash crop to avoid competition between the two crops (Craighead 2016). However, some common cover crop species are grown simultaneously with the cash crop as “trap crops,” in which a small percentage of a field is grown with cover crops (Hokkanen 1991). This trap crop can protect the cash crop by preventing pests from reaching the crop, enhancing natural enemies (Bugg and Waddington 1994), or by concentrating pests in the cover-cropped area so when the cover crop is terminated, the pests also will be destroyed (Hokkanen 1991).

Typically, cover crops fall into three functional groups: cereals or grasses, legumes, and brassicas (Florence 2016, Salon 2012, Sykes 2019). Cereals have higher carbon/nitrogen (C/N) ratios compared to legumes so they decompose slowly and generally provide greater weed suppression for the cash crop (Salon 2012, Sykes 2019). However, they can also use available nitrogen, leaving less for the cash crop (Florence 2016, Salon 2012, Sykes 2019). Legumes are nitrogen fixers, so they can provide a greater amount of nitrogen when terminated, but they decompose quickly making them less effective at weed suppression (Salon 2012, Snapp et al. 2005, Sykes 2019). They can also provide a source of nutrients for foraging pollinators. Brassicas can break up soil compaction with a unique tap root (Chen et al. 2014, Salon 2012, Sykes 2019). Some brassicas, as well as cereal rye, are allelopathic and exude chemicals that can

prevent weed germination and reduce soil-dwelling pathogen populations (Salon 2012, Sykes 2019). These allelopathic compounds can also be toxic to some insects and nematodes (Haramoto and Gallandt 2004). However, some studies have shown that the use of cover crops that exhibit allelopathy, such as rye and wheat, can reduce the growth of the cash crop (Allen et al. 2012, Shekoofa et al. 2020).

Cover cropping is sometimes used in other agricultural cash crops, such as corn and cotton (Eckert 1988, Koch et al. 2012, McClure et al. 2017, Smith et al. 1988). The extent of the ecological benefits that cover crop species can provide when incorporated into a soybean production system is highly dependent on regional adaptation and adaptation to rotation systems, which can vary in timing of cover crop establishment and termination (Sykes 2019). These adaptations mostly rely on management practices, especially time of planting (Sykes 2019). Choosing a cover crop species that is poorly adapted to its production system reduces the return on investment (Sykes 2019).

In recent years, growers in Tennessee have had an increased interest in the use of cover crops with soybean (Craighead 2016, Flinchum 2001). When introducing cover cropping to an established row crop system, it is important to achieve a balance between ecological benefits and economic returns (Sykes 2019). Thus choosing the right crops for the right system is vital. A mixture of several cover crop species is often used (Florence 2016, Salon 2012, Sykes 2019, White and Barbercheck 2017), but potential cover crops must first be evaluated individually to determine their effectiveness (Bugg and Waddington 1994, Craighead 2016, Hooks and Johnson 2003, McClure et al. 2017, White and Barbercheck 2017). It is imperative to know which species of pests and beneficials are present on each crop species, because each crop creates its own unique system with its own unique complex of organisms. One crop may be more attractive to

certain pests. For example, many clover species are a poor host for soybean cyst nematode (*Heterodera glycines* Ichinohe), while hairy vetch (*Vicia villosa* Roth) is a good host for this nematode (McClure et al. 2017).

Even though cover cropping provides a wealth of benefits, some negative aspects to cover cropping exist. One such limitation of cover cropping is that, in traditional cover cropping, growers must use valuable time and resources on a cover crop which is not harvested. As previously mentioned, certain species of cover crops can actually increase populations of certain pests (McClure et al. 2017). If the cover crop attracts a pest that also happens to be a pest species of the cash crop, then that cover crop can actually endanger the cash crop yield.

Another issue with traditional cover cropping involves a pest that has been steadily increasing in importance, slugs. Slugs can actually be pests of many crops, such as alfalfa (Grant et al. 1982), corn, and beans (Hammond 2000). They inflict the most damage during crop establishment and early growth in the spring and fall (Douglas and Tooker 2012, Hammond 2000). Slug damage is typically most severe under cool, wet conditions, which slow crop growth while slugs remain active (Douglas and Tooker 2012, Grant et al. 1982). They can be difficult to control because only a limited number of management tactics are currently available (Douglas and Tooker 2012). In soybean, slugs defoliate leaves (Hammond 1985, 2000) by creating craters in cotyledons and ragged holes in leaves, but plants die when the apical meristem is killed. In small numbers, slugs do not cause many problems, but in large numbers, they can cause severe enough damage to require replanting (Hammond 1985).

Slug damage to some crops has shown to be heaviest in no-tillage systems (Grant et al. 1982, Hammond 1985). The implementation of no-tillage results in less ground disturbance which would otherwise disturb slugs already present in the system. Increased slug incidence in

no-tillage systems is particularly a major concern for soybean growers in Tennessee, as nearly all soybean grown in Tennessee is part of a no-tillage system (Flinchum 2001, UT Crops 2020). In past years, slugs were typically not considered a major pest of soybean (Hammond 1985). In recent years, however, issues with slugs in soybean have seemingly increased (Ernest 2017, Hammond 2000, Stewart 2017, 2018). One possible explanation for this escalation in concern for slugs could potentially be the increased interest and applied use of cover crops in soybean systems. As more growers begin to shift the management of row crops to include conservation tillage methods, slugs are becoming increasingly important as crop pests (Douglas and Tooker 2012). Typically, when cover crops are terminated, they are left in the field as “dead mulch” (Jackson and Harrison 2008, Mangan et al. 1995, Vernavá et al. 2004). As the biomass of this dead mulch begins to degrade, it acts as a fertilizer and provides a source of added nutrients to the cash crop as it grows. However, leaving dead mulch in a system has also shown to increase the incidence of slugs and other pests (Mangan et al. 1995, Vernavá et al. 2004). Thus, the traditional method of cover cropping is not without its flaws. However, a newer approach of cover cropping (i.e., dual-use cover cropping) could potentially help to combat some of the shortcomings associated with traditional cover cropping.

Dual-use Cover Crops

Dual cropping is the use of dual-purpose cover crops that are harvested as a forage crop prior to cash crop planting (Gesch et al. 2014). Dual cropping provides more immediate economic advantages to growers because they are profiting from both the cover crop and the cash crop (Gesch et al. 2014). To ensure that a cover crop has minimal residue and can be successful as a dual-purpose crop, the following criteria must be met: 1) it should be easy to establish; 2) it should have a rapid growth rate so as to provide ground coverage quickly; 3) it

should produce a sufficient quantity of dry matter for maintenance of residues; 4) it should be disease resistant and not act as a host for diseases of the cash crop; 5) it should be easy to kill; and 6) it must be economically viable (Reeves 2018). Harvesting cover crops as dual-purpose crops has other added benefits. Dual-purpose crops can also act as trap crops. When the cover crops are harvested, the canopy- and stem-dwelling insects residing in them will be removed along with the cover crops. By removing a cover crop for forage, growers also eliminate dead mulch from the field, which could potentially help to reduce slug and other pest incidences within the cash crop.

A dual-cropping system also has some disadvantages to traditional cover cropping. The removal of dead mulch also removes much of the added source of nutrients for the cash crop that would have been provided by the cover crop if it had remained in the field. By harvesting the cover crop rather than leaving it in the field, there are added costs in the time and effort that it takes to harvest (Coombs et al. 2017, Hartwig and Ammon 2002, Reeves 2018). Depending on the cover crop species, the profit from the harvest of the cover crop may not be worth the effort of harvesting.

The development of management practices and alternative crop rotations to improve the compatibility between cover crops and crop rotation in production systems is something that has not been studied in depth (Reeves 2018). Dual-use cover cropping systems, in conjunction with proper crop rotations, may develop into a reliable long-term method of pest control to enhance profitability. Currently, dual cropping has primarily been studied using cover crops for grazing rather than for harvest (Bell et al. 2015). Dual cropping is still a relatively new method, so little research has been conducted with harvested dual-cropping systems, particularly in Tennessee. Likewise, traditional cover cropping has been used commonly with soybean, but little is known

about soybean as part of a dual-purpose cropping system. Even less research has been conducted to compare the success of traditional cover cropping to dual cropping.

Research Objectives

The primary focus of this study is to determine if dual cropping can be an alternative method to the practice of traditional cover cropping for soybean systems in Tennessee. This research will also seek to identify important arthropod and slug populations specific to several individual cover crop species and to improve the understanding of how these species perform individually to identify the best potential mixtures of these cover crops. These concerns will be addressed by completing the following objectives:

- 1) Evaluate the impact of dual-use cover cropping on pest and beneficial arthropods,
- 2) Assess the influence of dual-use cover cropping on density and impact of slugs, and
- 3) Determine the influence of dual-use cover cropping and pests on soybean yield.

CHAPTER II

Evaluation of the Impact of Dual-use Cover Cropping on Pest and Beneficial Arthropod Populations

Introduction

Soybean was first introduced to the United States in 1765 by a colonist in Georgia (North Carolina Soybean Producers Association 2014a). After corn, soybean is now the second-most-planted field crop in the United States (USDA ERS 2017), and large amounts are grown in several southeastern states, including Tennessee. Soybean is the number one agricultural crop in terms of both number of hectares planted and in economic value in Tennessee (Smith 2017, USDA/NASS 2018). The use of sound and effective pest management strategies is the best way to ensure the protection of this important crop.

One method that many farmers are choosing to implement is cover cropping. A cover crop is a crop planted before the cash crop primarily for soil health benefits. Some studies have also found that cover cropping can reduce issues caused by some weeds, diseases, insects, and other pests that impact the cash crop (Clark 2008, McClure et al. 2017). However, less is known about potential positive or negative impacts of cover crops on diseases and insects. Some cover crops have been shown to increase beneficial arthropod populations, such as pollinators and predatory insects (Bugg and Waddington 1994, Clark 2008, Eberle et al. 2015, Schipanski et al. 2014). Cover cropping can also eliminate some of the need for fertilizers and pesticides (Schipanski et al. 2014, Snapp et al. 2005). The extent of the ecological benefits that cover crop species can provide is decidedly reliant on regional adaptation and adaptation to rotation systems, which can vary in timing of cover crop establishment and termination (Sykes 2019).

Achieving a balance between ecological benefits and economic returns is important when introducing cover cropping to an established row crop system (Sykes 2019). Choosing the right crops for the right system is crucial. A mixture of several cover crop species is often used (Florence 2016, Salon 2012, Sykes 2019, White and Barbercheck 2017), but it is important to evaluate potential cover crops individually to determine their effectiveness (Bugg and Waddington 1994, Craighead 2016, Hooks and Johnson 2003, McClure et al. 2017, White and Barbercheck 2017). Each cover crop has its own unique arthropod community. Therefore, it is essential to know the composition of pest and beneficial arthropods present within each crop species.

Cover cropping in the traditional sense can have some limitations. Growers must use valuable time and resources on a cover crop which is not harvested. However, a method called dual-use cover cropping could eliminate this issue. Dual-use cover cropping, or dual cropping, is the use of cover crops that are harvested as a forage crop prior to cash crop planting (Gesch et al. 2014). To ensure the success of a dual-purpose crop, the following criteria must be met: 1) it should be easy to establish; 2) it should have a rapid growth rate so as to provide ground coverage quickly; 3) it should produce a sufficient quantity of dry matter; 4) it should be disease resistant and not act as a host for diseases of the cash crop; 5) it should be easy to kill; and 6) it must be economically viable (Reeves 2018).

Currently, dual cropping has primarily been studied through the use of cover crops for grazing rather than for harvest (Bell et al. 2015). Relatively little research has been conducted with harvested dual-cropping systems, particularly in Tennessee. Similarly, traditional cover cropping has been used commonly with soybean, but little is known about soybean as part of a dual-purpose cropping system. Questions to be answered by this study include: Does the type of

cover crop management practice, whether traditional or dual-use, impact pest or beneficial arthropod populations and their densities? What composition of arthropods corresponds to each cover crop species? Does the species of cover crop affect pest or beneficial arthropod populations and their densities?

Materials and Methods

Establishment of Research Plots

In 2018, a research study in the University of Tennessee Department of Plant Sciences was ongoing to evaluate the regional adaptation, impact on cash crop yield and quality, and ecological impacts among 17 cool-season annual cover crop monocultures under two crop rotation systems (corn/cover crop/soybean and soybean/cover crop/corn) (Bracey 2020). This study was conducted at two locations in Tennessee, where 216 corn/cover crop/soybean rotation plots were established. Of these plots, 108 were planted in Knoxville at the Plant Sciences Unit of the East Tennessee AgResearch and Education Center (ETREC) (Fig. 1), and 108 were planted in Spring Hill at the Middle Tennessee AgResearch and Education Center (MTREC) (Fig. 2). Plots at both locations were established using a randomized complete block design consisting of three replications of the 17 cover crop species and one no cover crop (control) plot using two cover crop management practices. These management practices include: 1) Cover crops terminated prior to soybean planting and not harvested (traditional cover crop termination) and 2) cover crops terminated prior to soybean planting and harvested as a forage crop (dual-use cover crop harvest). Each plot was 3.05 m x 9.14 m (10 ft x 30 ft). Cover crop and soybean planting dates, as well as harvesting and termination dates, for both years are listed in Table 1.

For this study, 5 of the 18 cover crop treatments were used including: no cover crop (control), cereal rye (*Secale cereale*) (positive control), canola (*Brassica napus*), crimson clover

(*Trifolium incarnatum*), and woollypod vetch (*V. villosa* Roth ssp. *dasycarpa*). Among these treatments, a grass, a brassica, and two legume species were represented (Fig. 1 and 2). Cereal rye was represented as a “positive control” because it is already a widely used and well-studied cover crop species (Bottenberg et al. 1997, Creamer et al. 1996, Eckert 1988, Koch et al. 2012, Laub and Luna 1991, Mangan et al. 1995, Ruffo et al. 2004, Smith et al. 1988, Tillman et al. 2004). Cover crop varieties and seeding rate information for both years are provided in Table 2, and information on experimental design related to cover crop, management practice, replication and plot number is listed in Table 3. In 2019, cover crops were terminated in mid-April, and soybean was planted in each plot in mid-May (Table 1). The soybean was harvested in early October. Seeding and fertility rates (both cover crops and soybean) were based on recommendations from UT Extension Publication “Forage and Field Crop Seeding Guide for Tennessee” (Bates et al. 2008) (Table 2). The soybean variety used for this study was Credenz 4548 LL at both locations in 2019 and Asgrow 53X0 in 2020. Because these plots were also used for another study, these varieties had an insecticide seed treatment. The same process for the establishment and harvest of cover crop plots and soybean was repeated at the same locations in 2020 (Fig. 3 and 4, Tables 1, 2, and 4).

Arthropod Sampling

To evaluate the impact of dual-use cover cropping on pest and beneficial arthropods, samples of arthropod populations were taken from each cover crop treatment mentioned above and the subsequent soybean from both management practices. Sampling of the cover crop treatments at the Knoxville location occurred weekly beginning in mid-March and ending in mid-April 2019, when cover crops were terminated. Sampling of the cover crops in 2020 began in early-April and ended in late April 2020. Sampling began later in 2020 (April) due to colder

temperatures lasting longer into the season, and ended when the cover crops were terminated. All cover crop samples were collected using a standard sweep-net (38 cm diameter). Collections consisted of three sets of five sweeps per plot in a line through the center of each plot. These sweep samples were placed in either 0.94 L or 3.78 L plastic bags, placed in an ice chest, and transferred to a laboratory, where they were processed and sorted at a later date. In the laboratory, sweep samples were sorted into four categories: 1) beneficial insects (including both pollinators and predatory insects), 2) pest insects, 3) incidental insects, and 4) spiders. Commonly-occurring pests and beneficial insects were identified to species. All others were identified to family with the exception of spiders.

Sampling of soybean began in early June and continued until early October at both locations in 2019 and 2020. Soybean sampling included the previously mentioned sweeping method, as well as sampling using beat-sheets (standard 1m² canvas). Beat-sheet sampling consisted of three samples per plot beginning in July when the soybean was tall enough to bend over the canvas. Once plants were bent over the sheet, they were beaten vigorously, and all beat-sheet samples were assessed into the four previously mentioned categories in the field rather than collected. A combination of sweep-net samples and beat-sheet samples were taken because they are the most common methods of sampling insects in soybean, and when implemented together, they provide a more complete assessment of arthropod incidence (Bechinski and Pedigo 1982, Turnipseed and Kogan 1976).

Sampling methods prior to cover crop termination and after soybean planting at the Spring Hill location were the same as those at the Knoxville location during the same time frame. However, plots at Spring Hill were sampled monthly rather than weekly. All samples

(sweep-net and beat-sheet) at both locations were always taken along the middle two rows of each plot to minimize edge effects.

Data Analysis

Totals for pest and for beneficial arthropods were averaged per treatment plot. An analysis of variance was performed using GLM in SAS 9.4 (Cary,NC). Tukey's HSD was used for mean separation. A P-value of less than 0.05 was used to determine statistical significance. The fixed effects were location, cover crop species, and cover crop management practice, for each year separately. Analyses of both sweep-net and beat-sheet samples compared average total number of pest arthropods by cover crop species; average total number of beneficial arthropods by cover crop species; average total number of pest arthropods by cover crop management practice; and average total number of beneficial arthropods by cover crop management practice. For these analyses, two primary categories (pest arthropods and beneficial arthropods) were used. Incidental insects were excluded from the analyses because they did not fit into pest or beneficial arthropods for soybean or any of the cover crop species used in this study. Pest arthropods included: Acrididae, Aphididae, *Cerotoma trifurcata* (Förster) (bean leaf beetle), other Chrysomelidae, Cicadellidae, *Languria mozardi* Latreille (clover stem borer), Curculionidae, *Dectes texanus* LeConte (Dectes stem borer), *Popillia japonica* Newman (Japanese beetle), *Megacopta cribraria* (Fabricius) (kudzu bug), Noctuidae, Pentatomidae (specifically stink bugs), *Lygus lineolaris* (Palisot de Beauvois) (tarnished plant bug), and *Spissistilus festinus* (Say) (threecornered alfalfa hopper). Beneficial arthropods included: Apidoidea (pollinators), *Geocoris spp.* (big-eyed bug), Carabidae, Coccinellidae, *Nabis spp.* (damself bug), *Orius insidiosus* (Say) (minute pirate bug), all parasitoid and predatory hymenoptera, *Podisus maculiventris* (Say) (spined soldier bug), spiders, and Syrphidae. These

categories were selected based on frequency of collection. Some species were collected, but not in large enough quantities to be included, such as *Blissus leucopterus* (Say) (true chinch bug).

Results and Discussion

2019

In 2019, when sampling began in early March, cover crops were only about 12 cm tall, and little biomass was present until April. When sampling closer to cover crop termination, all cover crops were flowering, which likely attracted more pollinators as well as other arthropods to the increasing biomass. Significant differences in the average total number of pest arthropods in sweep samples in cover crops was observed between the Knoxville and Spring Hill locations (Table 5 and Fig. 5). Significantly greater numbers of pest arthropods were collected from Spring Hill than from Knoxville. However, the only significant difference in average number of pests observed within each location was between canola and cereal rye at Spring Hill before cover crop termination and when combining pre-terminated cover crop data and post-planted soybean data (Table 6 and Fig. 5). The average total number of pest arthropods in sweep samples was not significantly different among cover crop species after soybean planting (Fig. 6). There were significant differences in the average number of pest arthropods between time of collection (whether the collections were taken before cover crops were terminated or after soybean was planted) (Table 5). At Knoxville, there was a significantly greater number of pest arthropods collected after soybean planting than before cover crop termination. However, at Spring Hill, a significantly greater number of pest arthropods collected before cover crop termination than after soybean planting. This difference was likely due to the large number of aphids that were collected before cover crop termination at Spring Hill.

The average total number of beneficial arthropods in sweep samples was not significantly different between cover crop species (Tables 6 and 7, Fig. 7 and 8). However, significant differences in the average number of pest arthropods between time of collection were observed (Table 7). At Knoxville, just like with pest arthropods, a significantly greater number of beneficial arthropods collected after soybean planting than before cover crop termination. At Spring Hill, also like with pest arthropods, a significantly greater number of pest arthropods were collected before cover crop termination than after soybean planting. This difference was likely due to the large number of aphid parasitoids that were collected before cover crop termination at Spring Hill.

For beat-sheet samples, the average number of pest arthropods was not significantly different among location or cover crop species (Tables 6 and 8, Fig. 9). However, the average number of beneficial arthropods was significantly different between locations but not among cover crops (Tables 6 and 9, Fig. 10). Beat-sheet samples were only taken after soybean was planted. Therefore, no comparisons could be made between time of collection for beat-sheet samples.

The total number of each pest and beneficial arthropod category for each cover crop species before cover crop termination (Tables 10 and 11) provide a general idea about the composition of arthropods that comprise each cover crop community. More than five times as many arthropods were collected in cover crops at Spring Hill (n=5,825) than at Knoxville (n=997) before cover crop termination (Tables 5, 10, and 11). This difference in number of arthropods is primarily due to large numbers of aphids and parasitoid/predatory hymenoptera at Spring Hill. However, after soybean planting, almost seven times as many arthropods were collected at Knoxville (n=8,551) than at Spring Hill (n=1,291) (Tables 5, 12, and 13).

At both locations, aphids were the dominant pest present among all cover crop species before cover crop termination, especially at Spring Hill (Table 10). The most common species of aphid found was *Acyrtosiphon pisum* (Harris) (pea aphid). Significantly greater numbers of aphids were found at Spring Hill than at Knoxville (Table 14). A significantly greater number of aphids were found in cereal rye and crimson clover than from all other cover crops at Spring Hill. There were also significantly more aphids collected before cover crop termination than after soybean planting at both locations (Table 14). This difference likely implies that the species of aphids that were collected before cover crop termination were not a typical soybean pest. A large number of aphids were found in the no cover control plots at Spring Hill. Cover crop species that had large numbers of aphids also had large numbers of wasps that were parasitoids of these aphids (primarily identified to be Braconidae) (Tables 11, 13, and 15). A significantly greater number of these parasitoids were collected from Spring Hill than from Knoxville (Table 15). This difference is likely because of the greater number of aphids in Spring Hill. There were also significantly greater number of parasitoids before cover crop termination than after soybean planting, likely because the majority of aphids were found before cover crop termination. There were significantly more Curculionidae collected from Spring Hill than from Knoxville (Table 16). Significantly greater numbers of Curculionidae were present in canola than in any of the other cover crop treatments at both locations (Table 10). A significantly greater number of Curculionidae were collected before cover crop termination than after soybean planting (Table 16). While parasitoid and predatory wasps were the most common beneficial arthropods at both locations prior to cover crop termination, Coccinellidae and spiders were also common beneficials (Table 11).

The total number of each pest and beneficial arthropod category for each cover crop species after soybean planting are represented in Tables 12 and 13. During this time, threecornered alfalfa hoppers were by far the most common pest at Knoxville and second most common at Spring Hill (Table 12). Although they were common in all cover crops, significant differences in density of threecornered alfalfa hoppers were found among cover crops (Table 17). They were significantly more abundant in crimson clover and woollypod vetch than in other cover crop treatments at Knoxville (Table 12). Significantly greater numbers of threecornered alfalfa hopper were present at Knoxville than Spring Hill (Table 17). Also, significantly greater numbers were collected after soybean planting than before cover crop termination. Cicadellidae, Noctuidae, and tarnished plant bug were also common pests at both locations after soybean planting (Table 12). Big-eyed bugs, Coccinellidae, damsel bugs, minute pirate bugs, and spiders were the most common predatory beneficial arthropods at both locations after soybean planting (Table 13). They were all distributed fairly evenly among all cover crops.

In 2019, the average number of pest or beneficial arthropods per sweep-net or beat-sheet samples were not significantly different between cover crop management practice (traditional or dual-use) at either location (Tables 5, 6, 7, 8, 9, and 18). The fact that there is not a significant difference in the average number of arthropods could imply that arthropod populations are not affected by cover crop management strategy. If this is true, it would mean that growers would not have to be concerned about whether different cover crop management strategies would result in problems with arthropods carrying over into the cash crop.

2020

In 2020, sampling did not begin until early April, when cover crops were just beginning to flower. By the time cover crops were terminated in late April, the cover crops were fully

flowering. The average number of pest arthropods per sweep-net sample differed significantly between locations, with significantly greater numbers collected in Spring Hill (Table 19). The average number of beneficial arthropods did not differ significantly between locations (Table 20). The average number of pest and beneficial arthropods per sweep sample was significantly different among cover crops (Tables 19 and 20). Pest densities in woollypod vetch were significantly greater than in all other cover crop species at the Knoxville location and greater in woollypod vetch and crimson clover than other cover crops at Spring Hill before cover crop termination (Fig.11). The average number of pest arthropods in sweep-net samples were significantly different between crimson clover and canola and between crimson clover and the no cover control, but only when combining pre-termination cover crop data and post-planting soybean data (Table 21). Average number of pest arthropods per sweep-net sample was significantly greater in crimson clover at Spring Hill than in all cover crop species at Knoxville and Spring Hill before cover crop termination, with the exception of woollypod vetch at Spring Hill (Table 21 and Fig. 11). The average number of pests also were not significantly different among cover crop species at either location after soybean planting (Fig. 12).

The average number of beneficial arthropods per sweep-net sample was significantly greater between woollypod vetch and all other cover crop species at Knoxville, but only when combining pre-termination cover crop data and post-planting soybean data (Table 21). The average number of beneficial arthropods in crimson clover also differed significantly from the no cover control at Knoxville only when combining pre-termination cover crop data and post-planting soybean data (Table 21). When separating these data into pre-terminated cover crop and post-planted soybean, the average number of pest arthropods per sweep-net sample was not significantly different among cover crop species at either location or between locations (Fig. 13

and 14). Significantly more pest arthropods were collected before cover crop termination than after soybean planting (Table 19). However, at the time of finalizing this thesis, fewer samples had been collected after soybean planting than before cover crop termination. Sampling will continue until the soybean is harvested.

The total number of arthropods collected in 2020 before cover crop termination was more similar between locations than in 2019 (Tables 10 and 11). The number of arthropods before cover crop termination was almost identical between Knoxville (n=1,548) and Spring Hill (n=1,586) (Tables 12 and 13). The total number of arthropods after soybean planting were also similar between Knoxville (n=389) and Spring Hill (n=547) (Tables 10 and 11). Aphids were still the most abundant pest at both locations in 2020 before cover crop termination and were significantly different among cover crops (Table 22). There tended to be a greater number of aphids in plots in which the cover crop species had more biomass (i.e., crimson clover, cereal rye, and woollypod vetch) (Tables 10 and 11). Unlike 2019, there was not a significant difference in aphid density between locations in 2020 (Table 22). However, just as in 2019, a significantly greater number of aphids were found before cover crop termination than after soybean planting in 2020. Also as in 2019, significantly more Curculionidae were collected from Spring Hill than from Knoxville (Table 23) and from canola than any other cover crop treatment (Table 10). Significantly greater numbers of Curculionidae also were collected before cover crop termination than after soybean planting (Table 23). Other common pests before cover crop termination included Chrysomelidae and Cicadellidae. A significantly greater number of Chrysomelidae were collected from Spring Hill than from Knoxville (Table 24). However, Cicadellidae density did not differ significantly between locations (Table 25). Cover crop significantly impacted numbers of Chrysomelidae and Cicadellidae (Tables 24 and 25), as

crimson clover and woollypod vetch had significantly greater numbers of Chrysomelidae and Cicadellidae compared to other cover crop species (Table 10). Significantly greater numbers of Chrysomelidae were found before cover crop termination, while significantly greater numbers of Cicadellidae were found after soybean planting (Tables 24 and 25). However, at the time of finalizing this thesis, fewer samples had been collected after soybean planting than before cover crop termination. Significantly greater numbers of pollinators (Apidoidea) were collected from Spring Hill than Knoxville and before cover crop termination (Table 26). Significantly more Apidoidea were present in canola and crimson clover plots, which were both flowering at the time of collections (Table 11). The most common predatory arthropods before cover crop termination were big-eyed bugs, Coccinellidae, and Syrphidae (Table 12). Significantly greater numbers of each of these predators were found before cover crop termination than after soybean planting. While there was not a significant difference in big-eyed bug density between locations (Table 27), significantly greater numbers of Coccinellidae and Syrphidae were found at Knoxville than at Spring Hill (Tables 28 and 29). Because a significantly greater number of pest arthropods, especially aphids, was found at Spring Hill, the greater numbers of Coccinellidae and Syrphidae were expected (Table 19). Significantly greater numbers of big-eyed bugs and Coccinellidae were found in crimson clover and woollypod vetch than in other cover crops, probably resulting from prey food preferences (Table 12). Significantly greater numbers of Syrphidae were found in woollypod vetch than in any other cover crop treatment (Tables 12 and 29).

After soybean planting, Chrysomelidae, Cicadellidae, and threecornered alfalfa hoppers were the most common pests in 2020, primarily in the soybean plots that had previously contained crimson clover, cereal rye, and woollypod vetch (Table 12). While significantly

greater numbers of Chrysomelidae were collected before cover crop termination, they were still the second most common pest after soybean planting. Significant differences in threecornered alfalfa hopper density were found between locations and between time of collection (Table 30). Significantly greater numbers of threecornered alfalfa hoppers were collected from Spring Hill and after soybean was planted (Tables 10 and 12). Tarnished plant bug was also a common pest in all cover crop plots except for canola, but only at Knoxville (Table 12). The most common beneficial arthropods after soybean planting were big-eyed bugs, minute pirate bugs, and spiders at both locations (Table 13). Most of these beneficials were distributed fairly evenly among all of the cover crop species at both locations. However, minute pirate bug densities significantly differed among cover crops, as significantly greater numbers were found in woollypod vetch than in cereal rye and after soybean was planted (Tables 13 and 31). These numbers might be due to a large number of Cicadellidae also present in these plots during the same time (Table 12). Cicadellidae density did not significantly differ between locations, however, a significantly greater density of minute pirate bug was found at Spring Hill.

In 2020, the average number of pest arthropods per sweep-net sample was not significantly different between cover crop management practice (traditional or dual-use) at either location (Tables 18 and 19). The average number of beneficial arthropods per sweep-net sample was also not significantly different between cover crop management practice at either location (Tables 18 and 20). This absence of significance may imply that arthropod populations are not affected by cover crop management strategy, and growers would be able to choose a management strategy based on other factors that are right for them without having to be concerned about arthropod problems. However, until all data from 2020 have been collected, these results are subject to change.

Summary

Overall, a greater number of both pest and beneficial arthropods were collected from sweep netting than from beat-sheets after soybean planting. This difference was in contrast to a previous study on evaluating sampling techniques for soybean insects that found beat-sheets to be a more effective method to predict insect populations (Marston et al. 1976). However, as previously mentioned, a combination of sweep netting and beat-sheets has been shown to provide a more complete representation of arthropod incidences (Bechinski and Pedigo 1982, Turnipseed and Kogan 1976).

Plots with woollypod vetch and crimson clover tended to both have more pest and beneficial arthropods before cover crop termination in both 2019 and 2020, while canola and the no cover control tended to have the least number of arthropods. This difference can likely be explained due to the fact that woollypod vetch and crimson clover tend to have more biomass compared to canola and the no cover control (Bracey 2020). However, it was unexpected that the no cover control also tended to have a high average number of pests and beneficials per sweep net at Spring Hill in 2019 both before cover crop termination and after soybean planting. In fact, the no cover control had the highest average number of pest arthropods per beat-sheet after soybean planting among all cover crop species (i.e., canola, crimson clover, cereal rye, and woollypod vetch) at Spring Hill in 2019. Only a small amount of biomass from winter vegetation and weeds remained in the no cover control plots (see Chapter III). Though it did not differ significantly from other cover crop species, a larger number of beneficials per sample were observed in the no cover control after soybean planting at Spring Hill in 2019. Beneficial arthropods analyzed for this study consisted mostly of predators that should only be present if there were pests for them to prey on. This finding may imply that cover cropping was effectively

aiding in the reduction of insect pests after soybean planting. Average numbers of pest and beneficial arthropods per sample tended to be higher at Spring Hill before cover crop termination in 2019. Average numbers of pest and beneficial arthropods per sample tended to be more evenly distributed among all cover crop species after soybean planting in 2019 and 2020. This even distribution makes sense because no significant differences in the average number of pest and beneficial arthropods were found among cover crop species after soybean planting, which could mean that the cover crop species used may not have an effect on arthropod populations after soybean planting. However, the insecticide seed treatment on the soybean varieties used may have altered the composition of insect communities after soybean planting. Insecticide seed treatments have shown to be effective at reducing certain soybean pests, such as bean leaf beetles, especially at early growth stages (Koch et al. 2005, Witkowski and Echtenkamp 1996). It is important to note that insecticide seed treatments were used in this study because they depict typical soybean plantings in Tennessee. Additionally, the plots used in this study were small (3.05 m x 9.14 m). It is likely that most arthropods were continuously moving between these small plots. Larger plots may have generated a more accurate representation of insect populations in these types of systems.

No significant differences in the average number of pest arthropods per sample between cover crop management practice (traditional or dual-use) were found at either location in 2019 or 2020, which could imply that arthropod populations are not affected by cover crop management strategy. However, it is still important to know the density and composition of arthropod communities with different cover crop species, particularly if the cover crop will be harvested. These data can provide useful information to growers about what cover crops to select for when considering arthropods. If a grower is experiencing issues with a certain pest, they should

consider if a cover crop species could intensify the problem. For instance, if a grower has had issues with Curculionidae pests in the past, data from this study show that they should reconsider the use of canola as a cover crop. If a grower wants to attract more pollinators, a flowering cover crop species is a good option.

An important note on the 2020 study is that, at the time of finalizing this thesis (mid-July), only one sampling date had been processed for sweep samples after soybean planting at both locations, and no beat-sheet samples had been collected. Upon analysis of all sweep-net and beat-sheet samples after soybean harvest in 2020, the results could potentially change. Further research is still needed to fully understand the impact of dual-use cover cropping on arthropod populations in soybean.

CHAPTER III

Assessment of Dual-use Cover Cropping on Density and Impact of Slugs

Introduction

As previously stated in Chapter I, soybean is a crop that is vital to Tennessee as the number one agricultural crop in the state (Smith 2017, USDA/NASS 2018). This importance to the Tennessee agricultural economy makes the protection of soybean through the use of effective pest management strategies a primary concern. By implementing the use of cover crops, growers can reduce some of the issues caused by weeds, diseases, insects, and other pests (Clark 2008, McClure et al. 2017). However, cover crops can also contribute problems of their own.

One issue with traditional cover cropping is that it has the potential to increase slug incidence. A limited number of management tactics are currently available for the control of slugs (Douglas and Tooker 2012). In soybean, slugs defoliate leaves, and in large densities, they can cause severe enough damage to require a second planting (Hammond 1985). In recent years, damage caused by slugs has become an increasing problem in soybean (Ernest 2017, Stewart 2017, 2018). The increased interest and implementation of cover crops may have contributed to greater slug incidence. In traditional methods of cover cropping, when cover crops are terminated, they are left in the field as “dead mulch” (Jackson and Harrison 2008, Mangan et al. 1995, Vernavá et al. 2004). The resulting biomass left on the ground from this dead mulch has shown to increase the incidence of slugs and other pests (Mangan et al. 1995, Vernavá et al. 2004). A combination of extra shade and moisture provided by cover crops combined with the use of no-tillage planting methods create an ideal condition for slugs (Douglas and Tooker

2012). As problems with slugs continue to rise, alternate forms of cover cropping should prove beneficial in combatting slug damage.

When implementing dual-purpose cover cropping, the cover crops are harvested. By removing the cover crop, the dead mulch that would have remained on the ground is also eliminated. The removal of this dead mulch could potentially result in a reduction of slug incidence after soybean is planted. However, by removing the dead mulch, nutrients that would have been added to the soil will also be removed. It is important to evaluate the effectiveness of different management and planting techniques and what effects they could have on slug populations. Questions to be answered by this study include: Do certain species of cover crops result in higher numbers of slugs? Does dual-use cropping lead to a decrease in slug incidence?

Materials and Methods

Slug Sampling

This study was described in Chapter II, which focused on pest and beneficial arthropods. Slugs also were assessed in those same plots. To determine the influence of dual cropping on the density and impact of slugs, slug incidence was assessed in each cover crop treatment and the subsequent soybean from both management practices. Sampling for slugs prior to cover crop termination at both Knoxville and Spring Hill occurred weekly in 2019 from late February until cover crops were terminated in mid-April and again after soybean was planted from late May until mid-June. Sampling in 2020 was conducted between early April until cover crops were terminated in late April and again after soybean planting from early-to-mid-June.

To sample for slugs, a mixture of beer and oatmeal in a ratio of roughly two parts beer to one part oats was placed in a 100 mm × 15 mm Petri dish (Fig. 15). Three of these slug traps were evenly spaced in a line along the center of each plot. The traps were placed in the plots in

the afternoon, left overnight, and remained until the following morning, when the number of slugs was recorded for each corresponding plot. When inspecting for slugs, in addition to any slugs present in the trap, slugs within a 0.61 m (2 ft) radius of the trap were also recorded, including any slugs under a trap. Approximately 30 seconds was spent to search for slugs within 0.61 m of each trap.

Data Analysis

An analysis of variance was performed using the GLM in SAS 9.4 (Cary,NC). Tukey's HSD was used for mean separation. A P-value of less than 0.05 was used to determine statistical significance. The fixed effects were location, cover crop species, and cover crop management practice.

Results and Discussion

2019

The slug species found in this study was the marsh slug, *Deroceras leave* Muller. In 2019, slugs were sampled on five dates at Knoxville and three dates at Spring Hill before cover crop termination (i.e., before soybean was planted). After soybean was planted, slugs were sampled on three dates at Knoxville and two dates at Spring Hill. Slugs were only sampled until soybean was between 12.7 and 15.24 cm (5 to 6 in) tall. At that point, slugs cannot cause a sufficient amount of damage to injure the soybean. They inflict the most damage during crop establishment and early growth in the spring and fall (Douglas and Tooker 2012).

The average total number of slugs collected over the entire sampling period was significantly greater at Knoxville than at Spring Hill (Table 32). In fact, almost 15X more slugs were collected at Knoxville (n=291) than at Spring Hill (n=20). Despite there being a greater number of slugs in Knoxville, slug incidence was still slow, especially when considering that 90

traps were sampled on eight different dates. Several reasons could help to explain this low slug incidence. Several of the sampling dates in 2019 had freezing temperatures overnight. Optimal temperatures for slugs are between 17 and 20° C (63 to 68° F) (Douglas and Tooker 2012). While slugs prefer cool, wet conditions (Douglas and Tooker 2012), they have been shown to reduce their activity in heavy rainfall (Grant et al. 1982). In 2019, heavy rainfall occurred early in the year at both locations. The Knoxville location may have simply had a denser slug population than Spring Hill. However, since few slugs were collected from both locations, it is likely that neither location possessed damaging populations of slugs.

Combined for both locations, the average number of slugs per trap was not significantly different among cover crop species (Table 32, Fig 16 and 17). However, because a significant difference between locations was found, each location was analyzed separately. The average number of slugs per trap was significantly different among cover crops at Spring Hill (Table 33) but not at Knoxville (Table 34). The average number of slugs were significantly different between cereal rye and the no cover control treatments at Spring Hill, but only when combining all slugs collected over the entire sampling period (Table 33).

Timing of slug collections, however, had a significant impact on densities of slugs collected between before and after crop termination at Knoxville (Table 32). In fact, 23X more slugs were collected before (n=279) cover crop termination than after (n=12). No significant differences in the numbers of slugs collected prior to cover crop termination and at Spring Hill were detected (Table 33). However, the number of slugs were significantly different prior to cover crop termination and after soybean planting at Knoxville (Table 34), as significantly greater number of slugs were found prior to cover crop termination. This difference in number of slugs could be because cover crops created more biomass and shade than that provided by the

soybean seedlings. Time between cover crop termination and soybean planting may have also been a factor in reduced slug density after planting. Cover crops were terminated two weeks prior to soybean planting at both locations. This time period provided two weeks with no living biomass for slugs to feed on in the plots, which may be a reason that fewer slugs were found after soybean was planted. Slugs may have left these plots to find suitable food in other areas. High numbers of slugs were collected from plots containing cereal rye, woollypod vetch, and crimson clover at both locations. These cover crops provided the most shade and the most biomass (Table 35). The average number of slugs was second highest in the no cover control plots at Knoxville before cover crop termination. Although shade and food was lacking in some areas of the control plots, slugs may have been attracted to the biomass (e.g., weeds and winter vegetation) that grew in these plots (Table 35). It is possible that these slugs were in nearby plots and were attracted to the traps in the control plots. However, the small size of the plots in this study (3.05 m x 9.14 m) may affect slug populations, as the slugs would be capable of moving freely between them.

The average number of slugs were also not significantly different between cover crop management practice (traditional or dual-use) at either location (Table 18). This lack of difference may suggest that harvesting a cover crop as a dual-use crop, thereby removing dead mulch, does not effect slug populations as originally predicted, which is in contrast to previous studies showing that dead mulch can lead to increased slug incidence (Mangan et al. 1995, Vernavá et al. 2004).

2020

In 2020, slugs were sampled on three dates at Knoxville and two dates at Spring Hill before cover crop termination. Sampling began later in 2020 (April) because cold temperatures

lasted later into the season. Like in 2019, after soybean was planted, slugs were sampled only until soybean was between 12.7 and 15.24 cm (5 to 6 in) tall. After soybean was planted, slugs were sampled on two dates at Knoxville and two dates at Spring Hill. Unfortunately, slug populations were sparse, and sufficient numbers of slugs were not collected to enable statistical analysis. Only one slug was collected at Knoxville over all five sampling dates. This slug was collected in woollypod vetch before cover crop termination. Only four slugs were collected at Spring Hill over all four sampling dates. Of these collected slugs, two were in woollypod vetch, one in cereal rye, and one in crimson clover all on the same collection date (April 21) before cover crop termination. On this date, cover crops were nearing full growth and were flowering. At this stage, woollypod vetch, cereal rye, and crimson clover had the most biomass among all cover crop treatments (Table 35), which may explain why slugs collected in 2020 were found in these crops.

Summary

Slug incidence was low among all cover crops at both Knoxville and Spring Hill in 2019 and 2020. This low incidence of slugs could be explained due to adverse weather conditions, such as cold and freezing temperatures and heavy rainfall. Both 2019 and 2020 had heavy rainfall early in the year at both locations. It is also possible that a large slug population was not present at either location used in this study. All of the slugs in 2019 and 2020 were visually identified to be the same species (the marsh slug, *Deroceras leave* Muller). In 2019, significantly greater numbers of slugs were collected prior to cover crop termination than after soybean planting. This difference in number of slugs could be because cover crops created more biomass and shade than the soybean seedlings. Time between cover crop termination and soybean planting may have also been a factor. At both locations, average slug incidence was greater in

cereal rye, woollypod vetch, and crimson clover than in canola or the no cover control plots. In fact, all of the slugs found in 2020 were found in these three cover crops. These occurrences could be explained due to the fact that these cover crop species provide the most shade and the most biomass (Table 35). However, due to the small size of the plots in this study (3.05 m x 9.14 m) slugs would have been capable of moving freely between plots. In 2019, the average number of slugs was second highest in the no cover control plots at Knoxville before cover crop termination. However, there was still some biomass in these plots in the form of weeds and winter vegetation.

In 2019, slug incidence was not significantly different between cover crop management practices. This absence of difference between management practices could mean that harvesting a cover crop as a dual-use crop does not have an effect on slug populations as originally predicted, which differs from the results of previous studies that show dead mulch can lead to increased slug incidence (Mangan et al. 1995, Vernavá et al. 2004). Further research is needed to determine the relationship between dual-use cover crops and slug populations, especially given the limited amount of slug data collected for this study. While the number of collected slugs for this study was low, the information provided from their collection has the potential to inform growers on which cover crops to select, particularly if slugs are a major pest within their production systems.

CHAPTER IV

Determining the Influence of Dual-use Cover Cropping and Pests on Cover Crop Biomass and Soybean Yield

Introduction

Soybean is a crop that has become essential to agricultural production in Tennessee (Smith 2017). In 2017, 3.36 metric tons of soybean were harvested per hectare across almost 688,000 harvested hectares in Tennessee with an estimated value of \$680.3 million, and in 2019, 3.16 metric tons were harvested per hectare across nearly 554,400 hectares (UT Crops 2020). Cover crops have the potential to become a strategy to protect soybean from some weeds, diseases, insects, and other pests (Clark 2008, McClure et al. 2017), but they also have the potential to increase yield by managing soil erosion and increasing soil fertility, soil quality, and biodiversity (Gesch et al. 2014). Some cover crops have been shown to increase beneficials, such as pollinators and predatory insects (Bugg and Waddington 1994, Clark 2008, Eberle et al. 2015, Schipanski et al. 2014). Cover crops can also aid in reducing the need for fertilizers and pesticides, which can reduce costs (Schipanski et al. 2014, Snapp et al. 2005). When choosing to implement cover cropping, achieving a balance between ecological benefits and economic returns becomes essential (Sykes 2019). Selecting the right crops for each unique system is crucial. However, traditional methods of cover cropping have certain limitations, such as using valuable time and resources on planting cover crops which are not harvested. Some cover crops also have the potential to increase issues with certain pests, which could decrease yield (McClure et al. 2017).

Dual cropping may have the potential to overcome some of the concerns with traditional cover cropping. By harvesting the cover crop before the cash crop is planted, dual cropping provides more immediate economic advantages to growers, who profit from both the cover crop and the cash crop (Gesch et al. 2014). Dual cropping still provides most of the same advantages as traditional cover cropping, however, harvesting the cover crop removes an added source of nutrients that would have been present for use by the cash crop. There are also added costs in time and effort to harvest the cover crop rather than leaving it behind (Coombs et al. 2017, Hartwig and Ammon 2002, Reeves 2018). If growers intend to implement dual-use crops, they need to consider these costs. Some cover crop species may simply not be profitable enough to justify harvesting.

The development of dual-use cover cropping systems in coordination with proper crop rotations could potentially become a reliable long-term method for both control of pests and for profitability. Currently, only a limited amount of research has been conducted with harvested dual-cropping systems, particularly in Tennessee. More research is needed to compare the success of traditional cover cropping to dual-use harvested crops. This study was designed to answer the following question: Is there a correlation between arthropod or slug densities and cover crop biomass or soybean yield?

Materials and Methods

Assessment of Cover Crop Biomass

This study was described in Chapter II, which focused on the impact of dual-use cover cropping on pest and beneficial arthropod populations. To determine the influence of dual cropping and the potential impact of pests (both insects and slugs) on soybean yield, biomass samples of cover crops were taken prior to termination, and soybean yield was measured at the

end of the season. Prior to cover crop termination, biomass from a randomly selected 0.09 m² area of each plot was trimmed and collected in paper bags. These biomass samples were weighed, dried at 65°C for 72 hours, and then weighed again to calculate dry matter. Biomass present in no cover control plots consisted of weeds and winter vegetation. Three dual-use plots did not contain sufficient amounts of biomass for collection and one sample was lost (Table 35). These samples were collected at both locations in mid-April 2019 and late April 2020.

Assessment of Soybean Yield

Soybean harvest occurred in early October in Knoxville and late September at Spring Hill in 2019 (Table 1). At this time (mid-July), soybean harvest has not occurred for 2020 but is expected to occur in early-to-mid-October. Soybean was harvested in the middle two rows of each four-rowed plot with a small plot combine. Total plot weight and moisture were recorded. Yields were adjusted to a per hectare basis and converted to standard crop moistures (13% for soybean).

Data Analysis

Correlations were used to investigate the relationship between arthropod or slug populations and cover crop biomass and between arthropod or slug populations and soybean yield. An analysis of variance was performed using the `cor.test` function in the R 4.02 programming language. Pearson's correlation coefficients (r) was used to test the relationships between arthropod and slug populations and cover crop biomass; and between arthropod and slug populations and soybean yield. Values close to ± 1 have a high degree of correlation.

Results and Discussion

2019

In 2019, a few plots at Spring Hill did not have sufficient cover crop biomass or soybean yield to harvest (Table 35). In this study, there were two weeks between cover crop termination and soybean planting. This delayed planting likely aided the soybean as it has been shown that planting cash crops immediately after cover crop termination can lead to increased seedling disease and reduced emergence, growth, and yield (Acharya et al. 2017). This two-week gap also likely minimized any allelopathic impacts that may have endangered soybean germination. Allelopathic effects on cash crops have shown to decrease as timing between cover crop termination and cash crop planting increase (Shekoofa et al. 2020).

The correlations between cover crop biomass and average number of pest arthropods for both sweep-net and beat-sheet samples, between cover crop biomass and average number of beneficial arthropods, and between cover crop biomass and average number of slugs all had low degrees of correlation at both locations (Table 36). Though correlation does not equal causation, these results could imply that the amount of cover crop biomass did not impact pest and beneficial arthropods and slugs among all cover crop species tested in this study. However, other than canola and the no cover control, all of the cover crop treatments used in this study had similarly large amounts of biomass, and even some canola plots had a lot of biomass (Table 35). Correlations may have been different if cover crop treatments that result in less biomass had been used.

Correlations between soybean yield and average number of pest arthropods for both sweep-net and beat-sheet samples, between soybean yield and average number of beneficial arthropods, and between soybean yield and average number of slugs all had low degrees of

correlation at both locations (Table 36). These correlations may imply that both pest and beneficial arthropods and slug populations did not impact soybean yield in 2019.

2020

At the time of writing this thesis (mid-July), no beat-sheet samples had been collected and the soybean had not been harvested for 2020. Because of insufficient numbers of collected slugs, no correlations were performed for slugs in 2020. While there was not a sufficient number of slugs to compare for 2020, the low slug incidence in 2019 and 2020 suggests that they would not have impacted cover crop biomass or soybean yield at either of the locations used for this study. As long as slugs do not kill seedlings, soybean can withstand moderate levels of defoliation without suffering significant yield loss (Hammond 2000). A correlation was performed between cover crop biomass and the average number of pest arthropods collected in sweep-net samples. A high degree of correlation was found at Knoxville and a moderate degree of correlation was found at Spring Hill (Table 36). A comparison between cover crop biomass and the average number of beneficial arthropods collected in sweep-net samples resulted in a high degree of correlation at Knoxville and a low degree of correlation at Spring Hill (Table 36). These correlations contrast the results from 2019, and may imply that both the number of pest and beneficial arthropods did impact the amount of cover crop biomass or that, vice versa, the amount of cover crop biomass affected the number of pest and beneficial arthropods. If pest and beneficial arthropods did impact the amount of cover crop biomass in 2020, they could also affect soybean yield. More will be learned about these correlations once all of the 2020 sampling and soybean harvest has been completed.

Summary

While all correlations only had low degrees of correlation in 2019, the correlations between both the average number of pest arthropods and cover crop biomass and between the average number of beneficial arthropods and cover crop biomass showed a strong correlation at Knoxville in 2020 and medium or close-to-medium correlation at Spring Hill. Though correlation does not equal causation, the 2019 results could imply that pest and beneficial arthropods and slugs did not impact the amount of cover crop biomass among all cover crop species tested and did not affect soybean yield. In contrast, the 2020 data imply that both the number of pest and beneficial arthropods did affect the amount of cover crop biomass. After all data for the growing season have been collected, correlations between arthropod populations and soybean yield will be made for 2020.

The insecticide seed treatment on the soybean varieties used may have protected yield, but could have also likely changed the composition of insect communities after soybean planting. Insecticide seed treatments have shown to be effective at reducing some soybean pests, such as bean leaf beetles, especially at early growth stages (Koch et al. 2005, Witkowski and Echtenkamp 1996). Therefore the seed treatment used in this study could have reduced numbers of bean leaf beetle, at least during the early growth of the soybean. Other arthropods, both pests and beneficials, were also potentially impacted. However, insecticide seed treatments are a commonly used tactic in soybean production systems in Tennessee, so it provided a practical assessment for this study.

Even though sufficient numbers of slugs were not found to compare for 2020, the low slug incidence in 2019 and 2020 suggests that they would not have impacted cover crop biomass or soybean yield at either of the locations used for this study. Further research may be able to

discover if dual-use cover cropping has an impact on slugs, but the data for this study was far too limited to develop a true assessment. Research is necessary in a system that has denser slug populations to make a true comparison between slug incidence and soybean yield.

This study showed that the average number of pest or beneficial arthropods was not significantly different between cover crop management practices (see Chapter II). A study conducted in conjunction with this one that used the same research plots showed that there was not a significant difference between cover crop management practice and soybean yield (Bracey 2020). This information could mean that even if arthropods have a different impact in dual-cropped soybean than in traditionally cover cropped soybean, that impact may not be significant.

CHAPTER V

Conclusions

Soybean was first introduced to the United States in 1765 in Georgia (North Carolina Soybean Producers Association 2014a), and is now the second-most-planted field crop in the United States (USDA ERS 2017). In Tennessee, soybean has become the number one agricultural crop for both number of hectares planted and economic value (Smith 2017, USDA/NASS 2018). In 2019, 3.16 metric tons were harvested per hectare across approximately 554,400 hectares in Tennessee (UT Crops 2020). The use of sound and effective pest management strategies is vital to ensure the viability of soybean in Tennessee. To this end, some farmers are choosing to implement cover cropping as a method to protect against some weeds, diseases, insects, and other pests impacting the cash crop (Clark 2008, McClure et al. 2017). Choosing the right crops for the right system is a fundamental decision. Though a mixture of several cover crop species is often used together (Florence 2016, Salon 2012, Sykes 2019, White and Barbercheck 2017), it is important to evaluate cover crop species individually to determine their effectiveness (Bugg and Waddington 1994, Craighead 2016, Hooks and Johnson 2003, McClure et al. 2017, White and Barbercheck 2017).

Cover cropping in the traditional sense is believed to have some limitations, such as time and resources spent on a crop that will not be harvested. The dead mulch left on the ground after cover crop termination has shown to increase the incidence of slugs and other pests (Mangan et al. 1995, Vernavá et al. 2004). Dual-use cover cropping has the potential to increase profits by also allowing growers to profit from the cover crop. The harvest of cover crops through dual-use cover cropping would also exclude dead mulch, potentially leading to a reduction of slug incidence after soybean is planted. However, the removal of cover crops may also impact yield

by eliminating the added nutrients provided from leaving these crops in the field. Thus, it is important to evaluate the effectiveness of different management and planting techniques.

Results from this study indicated that cover crop species with more biomass, such as woollypod vetch and crimson clover, tended to have more arthropods than canola and the no cover control. However, the average number of pests and beneficials per sample in the no cover control plots tended to be higher at Spring Hill in 2019 both before cover crop termination and after soybean planting. These results may imply that cover cropping effectively reduced numbers of some insect pests and increased some beneficials after soybean planting at this location. No significant differences were found for pest or beneficial arthropod populations among the four cover crop species after soybean planting, which could mean that the cover crop species used may not have an effect on arthropod populations after soybean planting. The average number of pest and beneficial arthropods per sample was also not significantly ($p>0.05$) different between cover crop management practice (traditional or dual-use) at either location in 2019 or 2020. This finding may imply that arthropod populations are not affected by cover crop management strategy.

Further research on the density and composition of arthropod communities present in different cover crop species is still important, especially if cover crops are harvested as a dual-use crop. Several factors could have impacted the arthropod data collected for this study. The insecticide seed treatment that was used on the soybean likely protected yield, but may have altered the composition of insect communities after soybean planting. However, this tactic was included in this study because it is commonly used in soybean production systems in Tennessee. Despite the randomized approach of plot establishment, on some occasions, the same cover crop species was established in two adjacent plots, which could have effectively acted as one large

plot. Additionally, most insects are fairly mobile and likely continuously moved between the small plots in this study. Larger plots may have yielded a more realistic representation of insect populations in these types of systems.

Slug incidence was low among all cover crops at both Knoxville and Spring Hill in 2019 and 2020. These low densities may have resulted from adverse weather conditions, such as rainfall and temperature, which were not conducive to slugs or may be simply due to sparse populations of slugs at these two locations. Of the collected slugs, more were found prior to cover crop termination than after soybean planting. This higher number could be because cover crops created more biomass and shade than the soybean seedlings. It may also be due, in part, to the fact that cover crops were terminated two weeks before soybean was planted, leaving a gap of time with no living biomass for slugs to feed on. Though it was not significant, at both locations, slug incidence was greater in cereal rye, woollypod vetch, and crimson clover, which were the cover crop species that provided the most shade and biomass. In 2019, the average number of slugs was not significantly different between cover crop management practices. This finding suggests that harvesting a cover crop as a dual-use crop, thereby removing dead mulch, does not have an effect on slug populations as originally predicted, which is in contrast to previous studies showing that dead mulch can lead to increased slug incidence (Mangan et al. 1995, Vernavá et al. 2004). As discussed previously, this study used small plots. The incorporation of additional studies using larger plots may be able to better define influence of dead mulch on slug incidence.

While all correlations only had a low degree of correlation in 2019, the correlations between both the average number of pest arthropods and cover crop biomass and between average number of beneficial arthropods and cover crop biomass showed a strong correlation at

Knoxville in 2020 and medium or close-to-medium correlation at Spring Hill. The results for this part of the study were inconclusive. More research is needed to determine relationships between arthropod or slug densities and cover crop biomass and between arthropod or slug densities and soybean yield. Low slug incidence in 2019 and 2020 would likely mean slugs would not have had an impact on cover crop biomass or soybean yield at either of the locations used for this study. This study found no significant difference between cover crop management practice and average number of pest or beneficial arthropods. A study in conjunction with this study using the same research plots showed no significant ($p>0.05$) difference between cover crop management practice and soybean yield (Bracey 2020). This information may imply that even if arthropod densities vary between traditionally cover-cropped soybean and dual-cropped soybean, they may not negatively impact soybean yield.

Further research is needed to better determine if dual-use cover cropping has an impact on slugs, especially given the limited amount of slug data collected for this study. While slug incidence in this study was low, the information provided from their collection has the potential to inform growers which cover crops to select. If issues with slugs already exist in a system, growers should avoid the use of cover crops or be prepared to manage them to reduce slug damage. More research is necessary in a system that has denser slug populations to make a true comparison between slug incidence and soybean yield. Upon analysis of all sweep-net and beat-sheet samples after the 2020 soybean harvest, the results of this study will be more complete. Additional research will be needed to fully determine the impact of dual-use cover cropping and arthropod populations on soybean yield. While, results would likely vary on a system by system basis, as results from both locations in this study were often different from one another, a greater

number of studies with similar objectives to this one will provide a more complete depiction of the potential success of dual-use cover cropping.

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APPENDIX

3.05 m												9.14 m
Block R3	625	626	627	628	629	630	631	632	633	634	635	636
	624	623	622	621	620	619	618	617	616	615	614	613
	601	602	603	604	605	606	607	608	609	610	611	612
Block R2	536	535	534	533	532	531	530	529	528	527	526	525
	513	514	515	516	517	518	519	520	521	522	523	524
	512	511	510	509	508	507	506	505	504	503	502	501
Block R1	425	426	427	428	429	430	431	432	433	434	435	436
	424	423	422	421	420	419	418	417	416	415	414	413
	401	402	403	404	405	406	407	408	409	410	411	412

Figure 1. Layout of short-season plots at Plant Sciences Unit of the East Tennessee AgResearch and Education Center (ETREC) in Knoxville, TN, 2018-2019. Shaded cells indicate plots used for this study. Plot numbers correspond to treatments listed in Table 3.

3.05 m												9.14 m
Block R3	625	626	627	628	629	630	631	632	633	634	635	636
	624	623	622	621	620	619	618	617	616	615	614	613
	601	602	603	604	605	606	607	608	609	610	611	612
Block R2	536	535	534	533	532	531	530	529	528	527	526	525
	513	514	515	516	517	518	519	520	521	522	523	524
	512	511	510	509	508	507	506	505	504	503	502	501
Block R1	425	426	427	428	429	430	431	432	433	434	435	436
	424	423	422	421	420	419	418	417	416	415	414	413
	401	402	403	404	405	406	407	408	409	410	411	412

Figure 2. Layout of short-season plots at the Middle Tennessee AgResearch and Education Center (MTREC) in Spring Hill, TN, 2018-2019. Shaded cells indicate plots used for this study. Plot numbers correspond to treatments listed in Table 3.

Table 1. Cover crop plot establishment and termination/harvest dates; soybean planting and harvest dates, 2018 to 2020.

Year	Location	Cover Crops		Soybean	
		Establishment	Termination	Planting	Harvest
2018-2019	ETREC ¹	12 Oct 2018	24 April 2019	9 May 2019	2 Oct 2019
	MTREC ¹	5 Oct 2018	18 April 2019	8 May 2019	25 Sept 2019
2019-2020	ETREC	11 Oct 2019	6 May 2020	14 May 2020	N/A
	MTREC	11 Oct 2019	1 May 2020	14 May 2020	N/A

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

Table 2. Cover crop variety and seeding rate information, 2018 to 2020.

Cover crop	Seeding rate (kg ha ⁻¹)	Planting depth (cm)	Variety	
			2018-2019	2019-2020
Clover, crimson	28.03	1.27	Dixie	Dixie
Vetch, woollypod	33.63	5.08	Lana	Lana
Cereal rye	168.15	5.08	VNS	VNS
Canola	8.97	1.27	Edimax CL	Edimax CL

Table 3. Replication number, cover crop species, cover crop management practice, and number of all short-season plots at the East Tennessee AgResearch and Education Center (ETREC) and Middle Tennessee AgResearch and Education Center (MTREC) in 2018-2019.

Location	Rep	Species	Mgt	Plot
ETREC ¹	1	Cereal Rye	T ²	408
ETREC	1	Clover, Crimson	T	412
ETREC	1	Canola	T	418
ETREC	1	Vetch, Woollypod	D	419
ETREC	1	No Cover	D	424
ETREC	1	Clover, Crimson	D	426
ETREC	1	Canola	D	429
ETREC	1	No Cover	T	433
ETREC	1	Cereal Rye	D	434
ETREC	1	Vetch, Woollypod	T	435
ETREC	2	Cereal Rye	D	502
ETREC	2	Vetch, Woollypod	D	510
ETREC	2	Clover, Crimson	D	512
ETREC	2	Canola	T	514
ETREC	2	No Cover	D	517
ETREC	2	Clover, Crimson	T	521
ETREC	2	Canola	D	524
ETREC	2	Vetch, Woollypod	T	527
ETREC	2	No Cover	T	530
ETREC	2	Cereal Rye	T	533
ETREC	3	No Cover	T	602
ETREC	3	Vetch, Woollypod	D	604
ETREC	3	Canola	T	609
ETREC	3	Vetch, Woollypod	T	617
ETREC	3	Clover, Crimson	D	618
ETREC	3	Clover, Crimson	T	620
ETREC	3	Canola	D	625
ETREC	3	Cereal Rye	D	627
ETREC	3	Cereal Rye	T	630
ETREC	3	No Cover	D	636
MTREC ¹	1	Canola	D	402
MTREC	1	Cereal Rye	T	404
MTREC	1	Clover, Crimson	D	407
MTREC	1	No Cover	D	413
MTREC	1	Vetch, Woollypod	T	414
MTREC	1	Vetch, Woollypod	D	415
MTREC	1	No Cover	T	416

Table 3 Continued

MTREC	1	Clover, Crimson	T	420
MTREC	1	Canola	T	425
MTREC	1	Cereal Rye	D	432
MTREC	2	Cereal Rye	D	503
MTREC	2	No Cover	D	506
MTREC	2	Canola	D	508
MTREC	2	Clover, Crimson	D	512
MTREC	2	No Cover	T	514
MTREC	2	Clover, Crimson	T	521
MTREC	2	Cereal Rye	T	523
MTREC	2	Canola	T	525
MTREC	2	Vetch, Woollypod	T	531
MTREC	2	Vetch, Woollypod	D	534
MTREC	3	No Cover	D	601
MTREC	3	Canola	T	609
MTREC	3	Clover, Crimson	T	613
MTREC	3	Canola	D	618
MTREC	3	No Cover	T	620
MTREC	3	Vetch, Woollypod	T	621
MTREC	3	Cereal Rye	T	622
MTREC	3	Clover, Crimson	D	626
MTREC	3	Cereal Rye	D	630
MTREC	3	Vetch, Woollypod	D	632

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

²Management practices were T=Traditional cover cropping and D=Dual-use cover cropping.

Block R3	325	326	327	328	329	330	331	332	333	334	335	336	9.14 m
	324	323	322	321	320	319	318	317	316	315	314	313	
	301	302	303	304	305	306	307	308	309	310	311	312	
Block R2	236	235	234	233	232	231	230	229	228	227	226	225	3.05 m
	213	214	215	216	217	218	219	220	221	222	223	224	
	212	211	210	209	208	207	206	205	204	203	202	201	
Block R1	125	126	127	128	129	130	131	132	133	134	135	136	9.14 m
	124	123	122	121	120	119	118	117	116	115	114	113	
	101	102	103	104	105	106	107	108	109	110	111	112	

Figure 3. Layout of short-season plots at Plant Sciences Unit of the East Tennessee AgResearch and Education Center (ETREC) in Knoxville, TN, 2019-2020. Shaded cells indicate plots used for this study. Plot numbers correspond to treatments listed in Table 4.

Block R3	325	326	327	328	329	330	331	332	333	334	335	336	9.14 m
	324	323	322	321	320	319	318	317	316	315	314	313	
	301	302	303	304	305	306	307	308	309	310	311	312	
Block R2	236	235	234	233	232	231	230	229	228	227	226	225	3.05 m
	213	214	215	216	217	218	219	220	221	222	223	224	
	212	211	210	209	208	207	206	205	204	203	202	201	
Block R1	125	126	127	128	129	130	131	132	133	134	135	136	9.14 m
	124	123	122	121	120	119	118	117	116	115	114	113	
	101	102	103	104	105	106	107	108	109	110	111	112	

Figure 4. Layout of short-season plots at the Middle Tennessee AgResearch and Education Center (MTREC) in Spring Hill, TN, 2019-2020. Shaded cells indicate plots used for this study. Plot numbers correspond to treatments listed in Table 4.

Table 4. Replication number, cover crop species, cover crop management practice, and number of all short-season plots at the East Tennessee AgResearch and Education Center (ETREC) and Middle Tennessee AgResearch and Education Center (MTREC) in 2019-2020.

Location	Rep	Species	Mgt	Plot
ETREC ¹	1	Clover, Crimson	T ²	106
ETREC	1	Cereal Rye	D	109
ETREC	1	No Cover	D	111
ETREC	1	No Cover	T	115
ETREC	1	Vetch, Woollypod	T	117
ETREC	1	Canola	T	120
ETREC	1	Canola	D	122
ETREC	1	Clover, Crimson	D	125
ETREC	1	Cereal Rye	T	126
ETREC	1	Vetch, Woollypod	D	128
ETREC	2	Vetch, Woollypod	D	211
ETREC	2	Canola	T	218
ETREC	2	Cereal Rye	D	219
ETREC	2	Clover, Crimson	T	223
ETREC	2	Cereal Rye	T	225
ETREC	2	Clover, Crimson	D	227
ETREC	2	Vetch, Woollypod	T	228
ETREC	2	No Cover	T	232
ETREC	2	No Cover	D	234
ETREC	2	Canola	D	236
ETREC	3	Clover, Crimson	T	303
ETREC	3	Clover, Crimson	D	305
ETREC	3	Vetch, Woollypod	T	307
ETREC	3	Canola	T	311
ETREC	3	Vetch, Woollypod	D	312
ETREC	3	Canola	D	315
ETREC	3	No Cover	D	319
ETREC	3	No Cover	T	324
ETREC	3	Cereal Rye	T	328
ETREC	3	Cereal Rye	D	332
MTREC ¹	1	No Cover	D	102
MTREC	1	Clover, Crimson	T	105
MTREC	1	Clover, Crimson	D	110
MTREC	1	No Cover	T	111
MTREC	1	Cereal Rye	D	113
MTREC	1	Vetch, Woollypod	T	121
MTREC	1	Canola	T	124

Table 4 Continued

MTREC	1	Vetch, Woollypod	D	127
MTREC	1	Canola	D	130
MTREC	1	Cereal Rye	T	131
MTREC	2	Cereal Rye	D	205
MTREC	2	Cereal Rye	T	209
MTREC	2	Clover, Crimson	D	213
MTREC	2	Canola	D	214
MTREC	2	No Cover	T	217
MTREC	2	No Cover	D	222
MTREC	2	Canola	T	223
MTREC	2	Vetch, Woollypod	D	224
MTREC	2	Vetch, Woollypod	T	228
MTREC	2	Clover, Crimson	T	231
MTREC	3	Canola	D	305
MTREC	3	No Cover	T	306
MTREC	3	Vetch, Woollypod	D	307
MTREC	3	Canola	T	315
MTREC	3	No Cover	D	324
MTREC	3	Cereal Rye	T	326
MTREC	3	Clover, Crimson	T	327
MTREC	3	Vetch, Woollypod	T	332
MTREC	3	Cereal Rye	D	333
MTREC	3	Clover, Crimson	D	335

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

²Management practices were T=Traditional cover cropping and D=Dual-use cover cropping.

Table 5. Model of average total number of pest arthropods per sweep-net sample, 2019, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	52355.9059	2013.6887	26.58	<.0001
Error	723	54773.3894	75.7585		
Corrected Total	749	107129.2953			

R-Square	Coeff Var	Root MSE	Average_Total_Pest Mean
0.488717	170.8739	8.703935	5.093777

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	14932.08434	14932.08434	197.10	<.0001
Cover	4	1018.06425	254.51606	3.36	0.0098
F_NF ¹	1	14.88723	14.88723	0.20	0.6577
C_S ²	1	4279.47013	4279.47013	56.49	<.0001
Cover*F_NF ³	4	1060.85733	265.21433	3.50	0.0077
Location*Cover	4	4481.23378	1120.30844	14.79	<.0001
Location*F_NF	1	6.62698	6.62698	0.09	0.7675
Location*Cover*F_NF	4	3731.65699	932.91425	12.31	<.0001
Cover*C_S	4	1910.14120	477.53530	6.30	<.0001
Location*C_S	1	20919.93807	20919.93807	276.14	<.0001
F_NF*C_S	1	0.94560	0.94560	0.01	0.9111

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

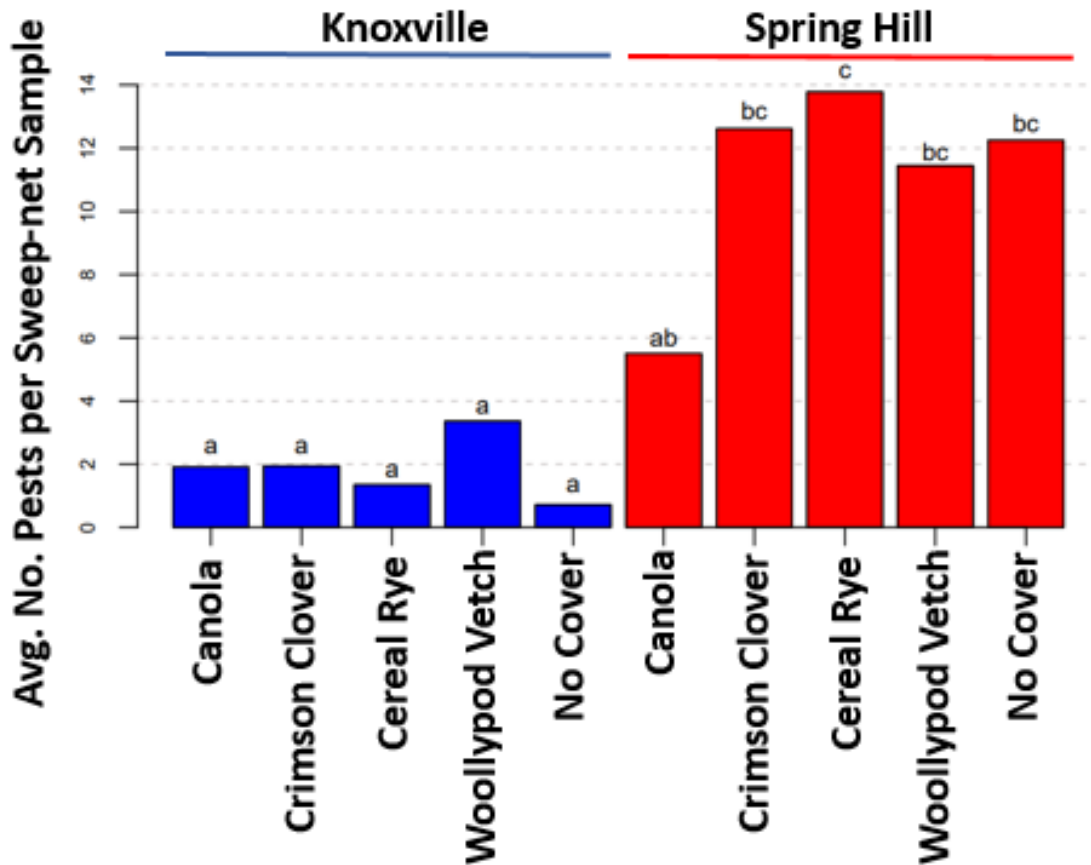


Figure 5. Influence of cover crop on average number of pest arthropods per sweep sample found in cover crops, 2019. Species with the same letter are not significantly different ($p > 0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC). Outliers were removed from MTREC data to better display these data; significance between cover crops was the same with or without outliers.

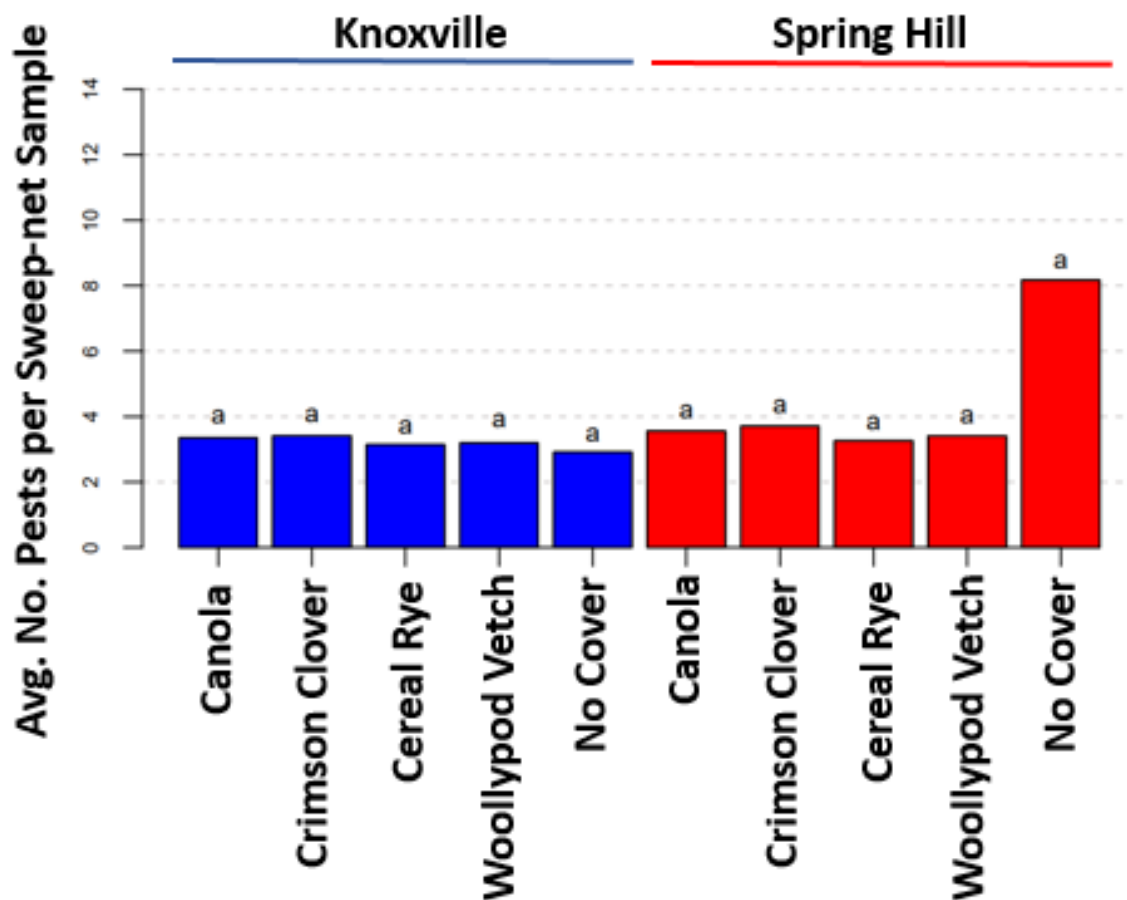


Figure 6. Influence of cover crop on average number of pest arthropods per sweep sample found in soybean, 2019. Species with the same letter are not significantly different ($p > 0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

Table 6. Influence of cover crop species on number of pest and beneficial arthropods and slugs at two locations in Tennessee, 2019.

2019 Cover Crop Comparison	Average Total Pest for Sweeps		Average Total Beneficial for Sweeps		Average Total Pest for Beat-sheet		Average Total Beneficial for Beat-sheet		Average Slug Incidence	
	ETREC ¹	MTREC ¹	ETREC	MTREC	ETREC	MTREC	ETREC	MTREC	ETREC	MTREC
	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)
Cereal Rye – Canola	0.933 ²	0.028³	1.000	0.988	0.888	1.000	1.000	0.999	0.191	0.197
Crimson Clover – Canola	1.000	0.180	0.997	0.463	0.457	0.990	1.000	1.000	0.348	1.000
No Cover – Canola	0.443	0.562	0.999	0.191	0.978	1.000	0.789	0.999	0.331	0.989
Woollypod Vetch – Canola	0.965	0.715	0.992	0.814	0.941	0.859	0.999	0.957	0.615	0.952
Crimson Clover – Cereal Rye	0.877	0.950	0.980	0.776	0.947	0.990	1.000	0.994	0.988	0.197
No Cover – Cereal Rye	0.900	0.605	0.987	0.452	0.997	1.000	0.768	1.000	0.941	0.064
Woollypod Vetch – Cereal Rye	0.593	0.450	0.964	0.977	1.000	0.859	0.999	0.865	0.975	0.604
No Cover – Crimson Clover	0.349	0.957	1.000	0.986	0.816	0.998	0.846	0.994	0.504	0.989
Woollypod Vetch – Crimson Clover	0.987	0.882	1.000	0.980	0.898	0.985	1.000	0.981	0.718	0.952
Woollypod Vetch – No Cover	0.131	0.999	1.000	0.814	1.000	0.926	0.894	0.865	0.637	0.753

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

² P-values represent combined pre-termination cover crop data and post-planting soybean data, with the exception of beat-sheet samples which were only collected after soybean planting.

³Bold text indicates significant difference between cover crop species ($p < 0.05$); Tukey's HSD.

Table 7. Model of average total number of beneficial arthropods per sweep-net sample, 2019, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	454.866620	17.494870	6.49	<.0001
Error	723	1947.476491	2.693605		
Corrected Total	749	2402.343111			

R-Square	Coeff Var	Root MSE	Average_Total_Beneficial Mean
0.189343	100.4009	1.641221	1.634667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	10.8801481	10.8801481	4.04	0.0448
Cover	4	12.2260741	3.0565185	1.13	0.3389
F_NF ¹	1	0.7259259	0.7259259	0.27	0.6038
C_S ²	1	122.1824243	122.1824243	45.36	<.0001
Cover*F_NF ³	4	8.3659259	2.0914815	0.78	0.5407
Location*Cover	4	24.6831852	6.1707963	2.29	0.0582
Location*F_NF	1	3.7925926	3.7925926	1.41	0.2358
Location*Cover*F_NF	4	14.1729630	3.5432407	1.32	0.2626
Cover*C_S	4	3.0006846	0.7501712	0.28	0.8919
Location*C_S	1	253.3349831	253.3349831	94.05	<.0001
F_NF*C_S	1	1.5017134	1.5017134	0.56	0.4555

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

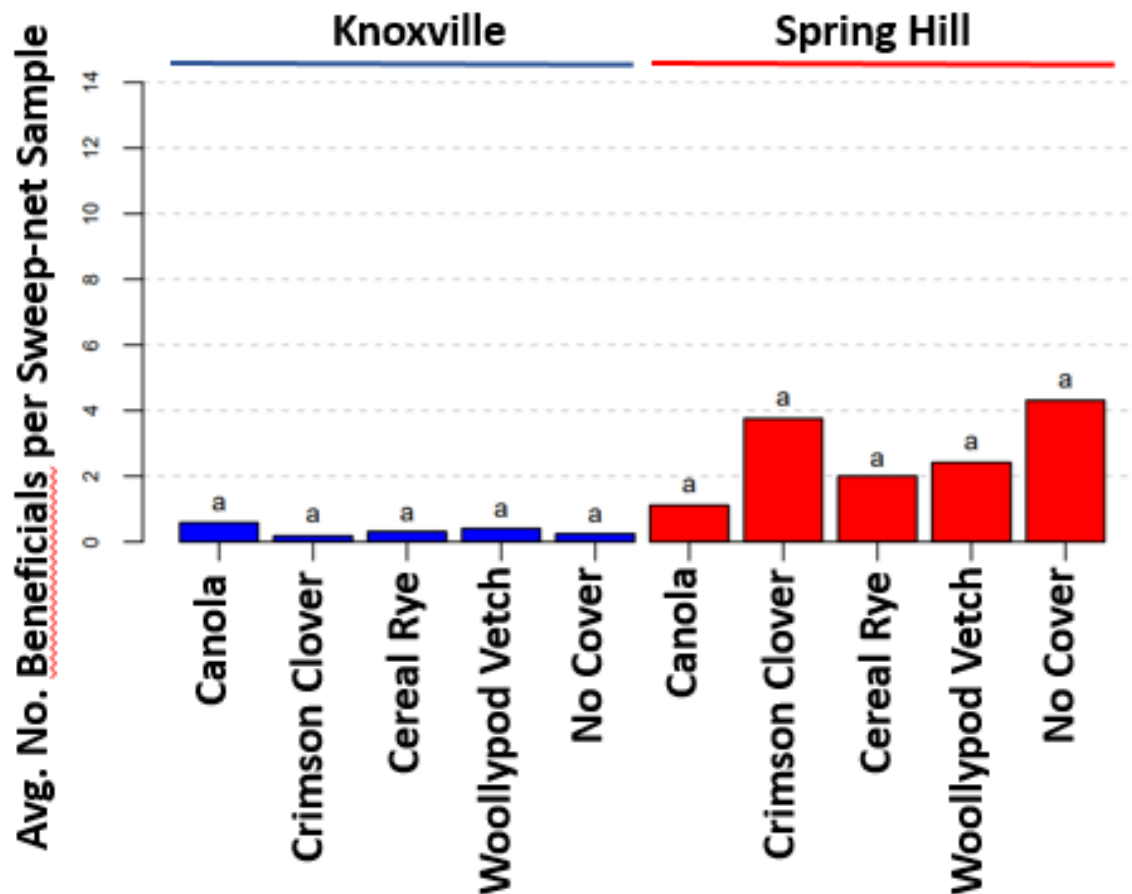


Figure 7. Influence of cover crop on average number of beneficial arthropods per sweep sample found in cover crops, 2019. Species with the same letter are not significantly different ($p > 0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

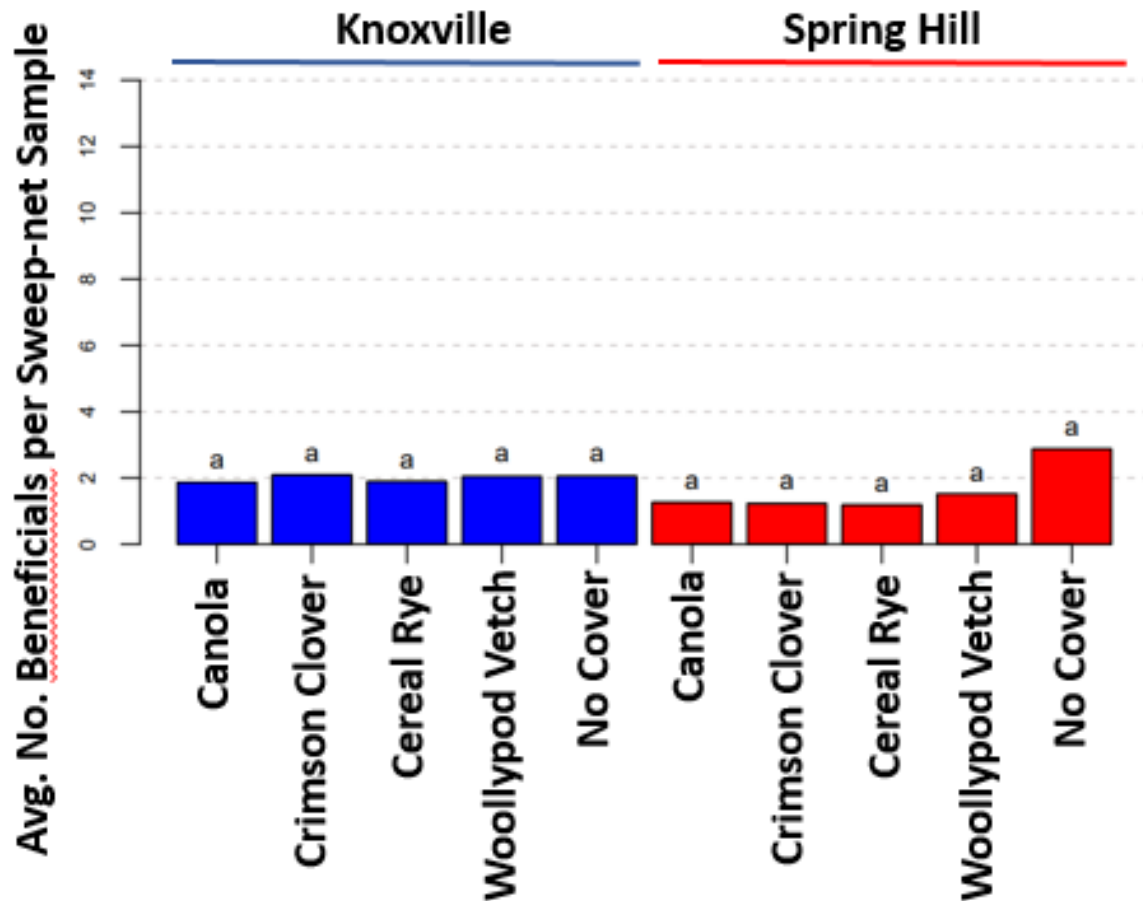


Figure 8. Influence of cover crop on average number of beneficial arthropods per sweep sample found in soybean, 2019. Species with the same letter are not significantly different ($p>0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC) Bars. shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

Table 8. Model of average total number of pest arthropods per beat-sheet sample, 2019, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	11.2927062	0.5943530	0.47	0.9719
Error	370	464.3951212	1.2551219		
Corrected Total	389	475.6878274			

R-Square	Coeff Var	Root MSE	Average_Total_Pest Mean
0.023740	78.67810	1.120322	1.423931

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	1.21713500	1.21713500	0.97	0.3254
Cover	4	2.60228615	0.65057154	0.52	0.7223
F_NF ¹	1	0.60284402	0.60284402	0.48	0.4887
Cover*F_NF ²	4	1.16069116	0.29017279	0.23	0.9208
Location*Cover	4	2.51401916	0.62850479	0.50	0.7352
Location*F_NF	1	0.11912648	0.11912648	0.09	0.7582
Location*Cover*F_NF	4	3.07660423	0.76915106	0.61	0.6537

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²The asterisk (*) denotes analysis of interaction between variables.

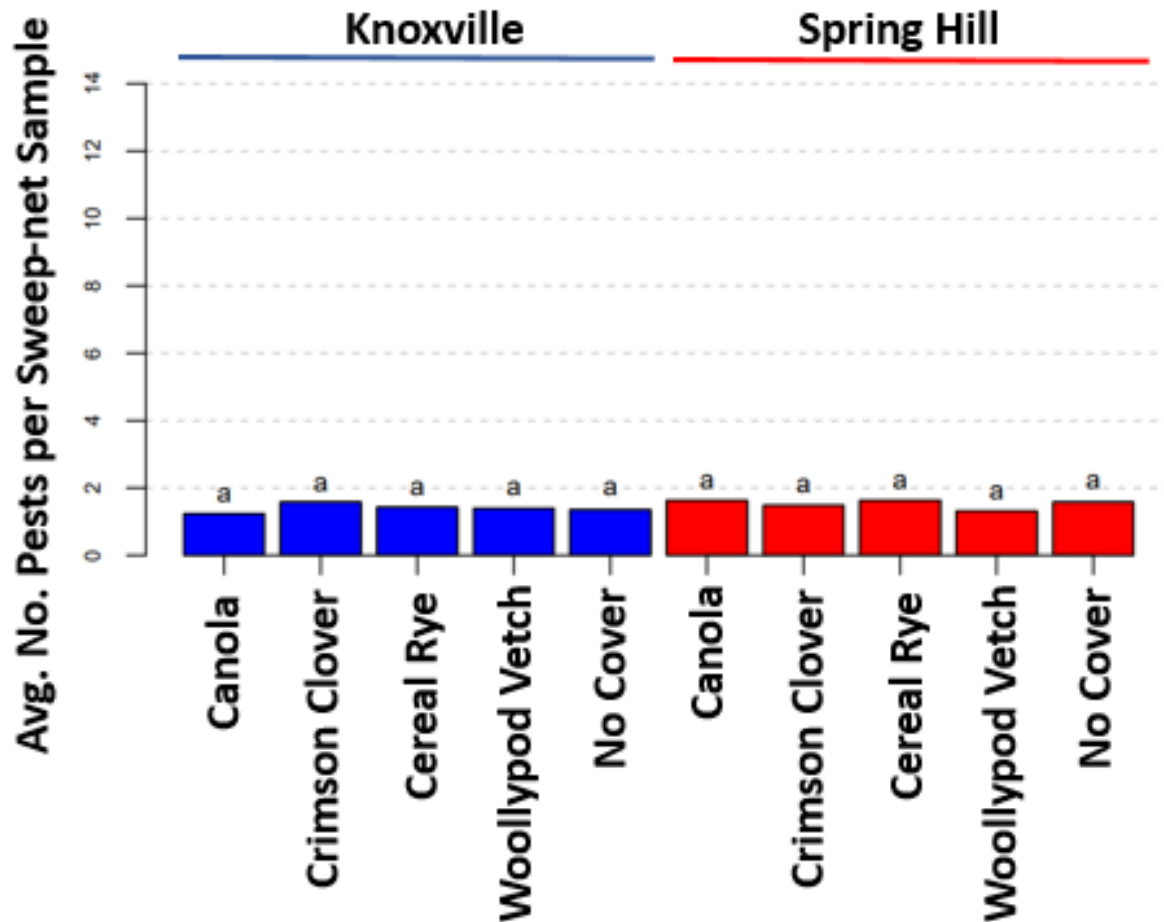


Figure 9. Influence of cover crop on average number of pest arthropods per beat-sheet sample found in soybean, 2019. Species with the same letter are not significantly different ($p > 0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

Table 9. Model of average total number of beneficial arthropods per beat-sheet sample, 2019, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	18.7206435	0.9852970	1.81	0.0203
Error	370	201.3876901	0.5442911		
Corrected Total	389	220.1083336			

R-Square	Coeff Var	Root MSE	Average_Total_Beneficial Mean
0.085052	96.98657	0.737761	0.760684

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	13.99618225	13.99618225	25.71	<.0001
Cover	4	0.86894832	0.21723708	0.40	0.8093
F_NF ¹	1	0.02849134	0.02849134	0.05	0.8192
Cover*F_NF ²	4	2.18519533	0.54629883	1.00	0.4055
Location*Cover	4	0.55303336	0.13825834	0.25	0.9071
Location*F_NF	1	0.00015187	0.00015187	0.00	0.9867
Location*Cover*F_NF	4	1.08864103	0.27216026	0.50	0.7357

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²The asterisk (*) denotes analysis of interaction between variables.

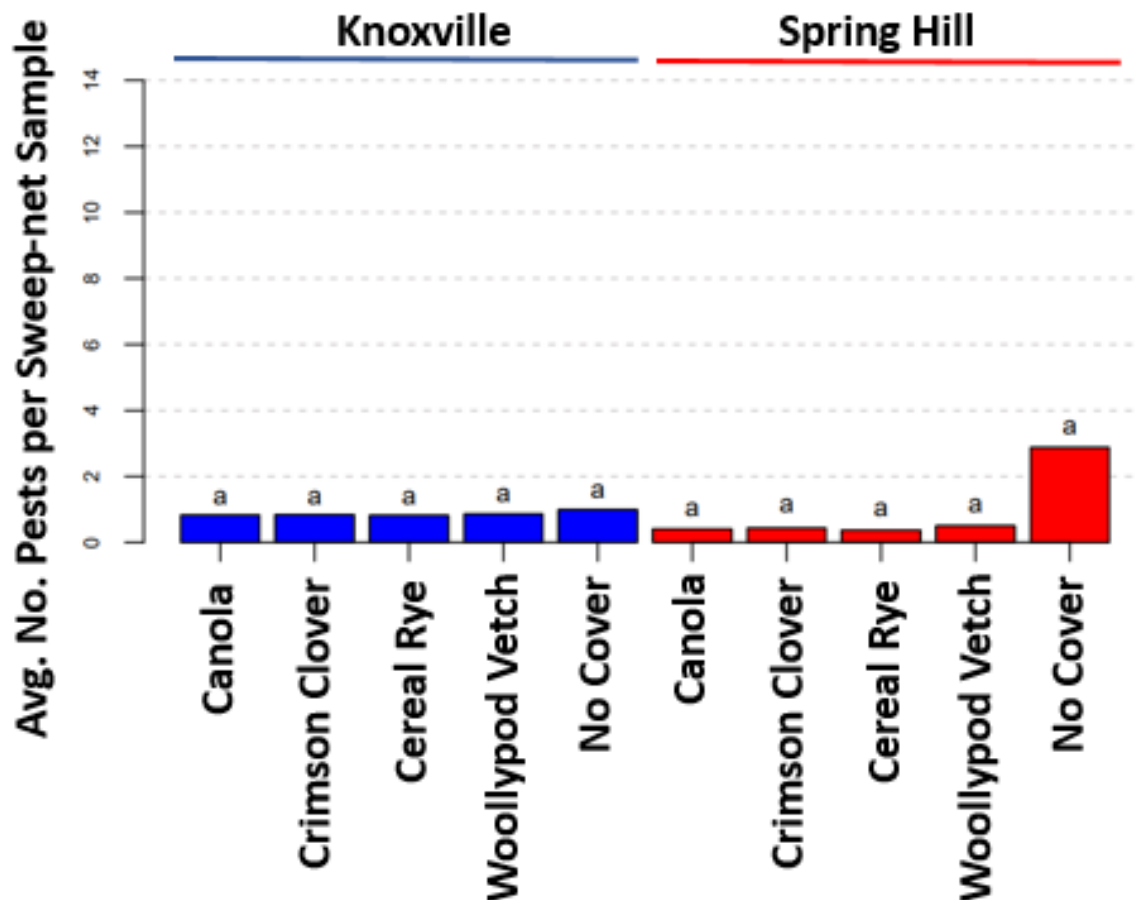


Figure 10. Influence of cover crop on average number of beneficial arthropods per beat-sheet sample found in soybean, 2019. Species with the same letter are not significantly different ($p>0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

Table 10. Influence of cover crop species on total number of pest arthropods in sweep nets before cover crop termination in cover crops at two locations in Tennessee, 2019 and 2020.

	Arthropod	ETREC ¹						MTREC ¹					
		Canola	Crimson Clover	Cereal Rye	Woollypod Vetch	No cover	Total	Canola	Crimson Clover	Cereal Rye	Woollypod Vetch	No cover	Total
2019	Acrididae	4	6	7	4	1	22	1	1	0	3	0	5
	Aphididae	127	158	109	253	59	706	146	1,384	1,831	886	1,022	5,269
	Bean leaf beetle	0	0	0	0	0	0	0	0	0	0	0	0
	Chrysomelidae	2	5	5	12	3	27	1	2	0	5	2	10
	Cicadellidae	0	4	3	21	1	29	0	6	3	1	1	11
	Clover stem borer	0	0	0	0	0	0	0	0	0	0	0	0
	Curculionidae	37	1	0	6	0	44	48	8	0	2	5	63
	Dectes stem borer	0	0	0	0	0	0	0	0	0	0	0	0
	Japanese beetle	0	0	0	0	0	0	0	0	0	0	0	0
	Kudzu bug	0	0	0	0	0	0	0	0	0	0	0	0
	Noctuidae	1	0	0	0	0	1	0	0	0	0	0	0
	Stink bug	0	0	0	0	0	0	0	0	0	0	0	0
	Tarnished plant bug	1	0	0	1	0	2	2	1	0	2	0	5
	Threecornered alfalfa hopper	0	1	0	5	0	6	0	5	0	3	1	9
	Total	172	175	124	302	64	837	198	1,407	1,834	902	1,031	5,372
2020	Acrididae	6	5	3	3	5	22	1	1	0	0	4	6
	Aphididae	19	148	80	362	21	630	75	155	174	122	20	546
	Bean leaf beetle	0	1	0	0	0	1	0	0	0	0	0	0
	Chrysomelidae	13	34	4	129	6	186	4	180	16	293	4	497
	Cicadellidae	2	26	6	15	7	56	1	24	2	8	1	36
	Clover stem borer	0	1	0	0	0	1	1	45	0	0	0	46
	Curculionidae	49	18	4	1	16	88	87	35	3	30	16	171
	Dectes stem borer	0	0	0	0	0	0	0	0	0	0	0	0
	Japanese beetle	0	0	0	0	0	0	0	0	0	0	0	0
	Kudzu bug	0	0	0	0	0	0	0	0	0	0	0	0
	Noctuidae	6	4	0	20	0	30	1	7	2	4	0	14
	Stink bug	0	2	1	0	0	3	2	7	1	1	1	12
	Tarnished plant bug	0	10	0	13	1	24	0	3	1	5	0	9
	Threecornered alfalfa hopper	0	12	0	3	0	15	0	8	0	2	0	10
	Total	95	261	98	546	56	1,056	172	465	199	465	46	1,347

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

Table 11. Influence of cover crop species on total number of beneficial arthropods in sweep nets before cover crop termination in cover crops at two locations in Tennessee, 2019 and 2020.

	Arthropod	ETREC ¹						MTREC ¹					
		Canola	Crimson Clover	Cereal Rye	Woollypod Vetch	No cover	Total	Canola	Crimson Clover	Cereal Rye	Woollypod Vetch	No cover	Total
2019	Apidoidea	6	0	0	2	0	8	4	1	0	1	1	7
	Big-eyed bug	1	0	0	1	0	2	0	4	0	0	1	5
	Carabidae	0	0	0	0	3	3	0	0	0	1	0	1
	Coccinellidae	3	3	1	3	0	10	3	31	1	11	7	53
	Damsel bug	0	0	0	0	0	0	0	0	0	0	0	0
	Minute pirate bug	0	0	0	0	0	0	0	0	0	0	1	1
	Parasitoid/predatory wasp	35	9	27	26	18	115	23	85	27	67	139	341
	Spined soldier bug	0	0	0	0	0	0	0	0	0	0	10	10
	Spider	3	4	0	5	3	15	7	11	0	5	5	28
	Syrphidae	5	0	0	2	0	7	3	2	0	1	1	7
	Total	53	16	28	39	24	160	40	134	28	86	165	453
2020	Apidoidea	6	13	0	2	1	22	16	23	1	3	0	43
	Big-eyed bug	0	15	1	23	0	39	0	23	0	15	0	38
	Carabidae	0	0	0	0	0	0	0	0	0	0	0	0
	Coccinellidae	4	25	12	52	1	94	1	19	2	13	3	38
	Damsel bug	0	1	0	0	0	1	0	1	0	0	0	1
	Minute pirate bug	0	0	0	0	0	0	0	0	0	0	0	0
	Parasitoid/predatory wasp	6	31	30	26	7	100	14	7	3	8	2	34
	Spined soldier bug	0	0	0	0	0	0	1	6	0	0	0	7
	Spider	2	9	12	4	4	31	8	13	18	6	7	52
	Syrphidae	17	9	4	174	1	205	3	2	1	20	0	26
	Total	35	103	59	281	14	492	43	94	25	65	12	239

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

Table 12. Influence of cover crop species on total number of pest arthropods in sweep nets after soybean planting in cover crops at two locations in Tennessee, 2019 and 2020.

	Arthropod	ETREC ¹						MTREC ¹					
		Canola	Crimson Clover	Cereal Rye	Woollypod Vetch	No cover	Total	Canola	Crimson Clover	Cereal Rye	Woollypod Vetch	No cover	Total
2019	Acrididae	64	74	59	78	71	346	9	9	8	11	9	46
	Aphididae	6	2	5	2	1	16	3	7	7	8	7	32
	Bean leaf beetle	9	12	9	2	12	44	25	12	20	7	9	73
	Chrysomelidae	96	73	90	58	92	409	31	24	24	17	16	112
	Cicadellidae	261	281	229	271	191	1,233	27	39	32	50	44	192
	Clover stem borer	5	3	1	4	1	14	5	5	1	0	5	16
	Curculionidae	1	0	1	3	3	8	1	1	1	1	0	4
	Dectes stem borer	1	0	0	1	1	3	4	3	1	5	3	16
	Japanese beetle	1	2	1	1	4	9	3	4	2	5	4	18
	Kudzu bug	46	37	57	45	55	240	3	7	5	8	4	27
	Noctuidae	143	171	138	139	131	722	37	25	21	23	29	135
	Stink bug	15	22	18	19	25	99	16	21	21	18	24	100
	Tarnished plant bug	108	141	87	143	80	559	3	6	5	5	7	26
	Threecornered alfalfa hopper	141	903	146	861	117	2,168	25	36	26	26	26	139
	Total	897	1,721	841	1,627	784	5,870	192	199	174	184	187	936
2020	Acrididae	0	4	3	3	1	11	20	21	18	21	18	98
	Aphididae	0	1	0	0	0	1	1	1	0	1	0	3
	Bean leaf beetle	0	0	0	0	0	0	0	0	0	0	1	1
	Chrysomelidae	1	20	23	6	11	61	4	10	40	7	1	62
	Cicadellidae	18	14	23	42	28	125	17	15	6	27	15	80
	Clover stem borer	1	1	0	0	0	2	0	2	2	2	0	6
	Curculionidae	0	0	0	0	0	0	0	1	0	1	0	2
	Dectes stem borer	0	0	0	0	0	0	0	0	0	0	0	0
	Japanese beetle	0	1	0	0	1	2	0	0	0	0	0	0
	Kudzu bug	0	1	2	0	4	7	0	0	0	0	0	0
	Noctuidae	2	0	3	0	2	7	3	8	2	6	1	20
	Stink bug	0	0	0	0	0	0	0	0	0	0	0	0
	Tarnished plant bug	0	3	8	6	4	21	0	0	0	0	0	0
	Threecornered alfalfa hopper	5	13	13	6	15	52	29	3	14	15	15	76
	Total	27	58	75	63	66	289	74	61	82	80	51	348

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

Table 13. Influence of cover crop species on total number of beneficial arthropods in sweep nets after soybean planting in cover crops at two locations in Tennessee, 2019 and 2020.

	Arthropod	ETREC ¹						MTREC ¹					
		Canola	Crimson Clover	Cereal Rye	Woollypod Vetch	No cover	Total	Canola	Crimson Clover	Cereal Rye	Woollypod Vetch	No cover	Total
2019	Apidoidea	7	12	5	4	11	39	2	1	3	2	0	8
	Big-eyed bug	175	198	178	214	244	1,009	20	18	15	23	21	97
	Carabidae		8	8	10	9	35	3	1	2	4	3	13
	Coccinellidae	44	41	40	60	43	228	10	6	5	2	5	28
	Damsel bug	98	103	104	86	102	493	4	6	3	1	3	17
	Minute pirate bug	55	40	31	48	43	217	9	11	10	10	9	49
	Parasitoid/predatory wasp	50	58	39	43	36	226	5	4	8	11	8	36
	Spined soldier bug	1	7	1	4	0	13	2	1	0	0	0	3
	Spider	72	95	104	80	63	414	13	18	18	29	25	103
	Syrphidae	2	2	0	1	2	7	0	0	0	0	1	1
	Total	504	564	510	550	553	2,681	68	66	64	82	75	355
2020	Apidoidea	2	1	1	2	1	7	0	0	0	0	0	0
	Big-eyed bug	3	8	7	1	9	28	7	10	2	8	10	37
	Carabidae	0	1	1	0	0	2	0	0	0	0	0	0
	Coccinellidae	1	3	3	1	1	9	1	0	0	0	0	1
	Damsel bug	2	3	5	1	2	13	0	0	0	1	0	1
	Minute pirate bug	4	3	0	2	1	10	4	2	2	23	14	45
	Parasitoid/predatory wasp	3	0	0	1	0	4	2	2	1	3	2	10
	Spined soldier bug	0	0	0	0	0	0	0	0	0	0	0	0
	Spider	1	10	8	4	4	27	27	23	21	19	15	105
	Syrphidae	0	0	0	0	0	0	0	0	0	0	0	0
	Total	16	29	25	12	18	100	41	37	26	54	41	199

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

Table 14. Model of total number of Aphididae per sweep-net sample, 2019, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	530470.3781	20402.7068	32.26	<.0001
Error	723	457210.2366	632.3793		
Corrected Total	749	987680.6147			

R-Square	Coeff Var	Root MSE	Aphididae Mean
0.537087	313.4513	25.14715	8.022667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	139714.5763	139714.5763	220.93	<.0001
Cover	4	10264.6213	2566.1553	4.06	0.0029
F_NF ¹	1	22.8813	22.8813	0.04	0.8492
C_S ²	1	90702.1347	90702.1347	143.43	<.0001
Cover*F_NF ³	4	8350.3653	2087.5913	3.30	0.0108
Location*Cover	4	42285.9087	10571.4772	16.72	<.0001
Location*F_NF	1	19.0403	19.0403	0.03	0.8623
Location*Cover*F_NF	4	33702.9380	8425.7345	13.32	<.0001
Cover*C_S	4	18552.6379	4638.1595	7.33	<.0001
Location*C_S	1	186796.8436	186796.8436	295.39	<.0001
F_NF*C_S	1	58.4305	58.4305	0.09	0.7612

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 15. Model of total number of parasitoid/predatory wasps per sweep-net sample, 2019, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	2050.827138	78.877967	11.34	<.0001
Error	723	5029.039529	6.955795		
Corrected Total	749	7079.866667			

R-Square	Coeff Var	Root MSE	Parasitoid_Predator_Wasp Mean
0.289670	278.5969	2.637384	0.946667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	484.0083333	484.0083333	69.58	<.0001
Cover	4	45.3733333	11.3433333	1.63	0.1646
F_NF ¹	1	3.6053333	3.6053333	0.52	0.4718
C_S ²	1	335.0256061	335.0256061	48.16	<.0001
Cover*F_NF ³	4	36.5146667	9.1286667	1.31	0.2638
Location*Cover	4	250.6766667	62.6691667	9.01	<.0001
Location*F_NF	1	16.5763333	16.5763333	2.38	0.1231
Location*Cover*F_NF	4	76.4953333	19.1238333	2.75	0.0274
Cover*C_S	4	78.5504040	19.6376010	2.82	0.0242
Location*C_S	1	715.8693939	715.8693939	102.92	<.0001
F_NF*C_S	1	8.1317340	8.1317340	1.17	0.2800

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 16. Model of total number of Curculionidae per sweep-net sample, 2019, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	202.0256364	7.7702168	10.29	<.0001
Error	723	546.0930303	0.7553154		
Corrected Total	749	748.1186667			

R-Square	Coeff Var	Root MSE	Curculionidae Mean
0.270045	547.7451	0.869089	0.158667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	15.55200000	15.55200000	20.59	<.0001
Cover	4	33.65866667	8.41466667	11.14	<.0001
F_NF ¹	1	0.00133333	0.00133333	0.00	0.9665
C_S ²	1	30.40969697	30.40969697	40.26	<.0001
Cover*F_NF ³	4	0.72533333	0.18133333	0.24	0.9157
Location*Cover	4	28.60800000	7.15200000	9.47	<.0001
Location*F_NF	1	0.06533333	0.06533333	0.09	0.7688
Location*Cover*F_NF	4	1.87466667	0.46866667	0.62	0.6480
Cover*C_S	4	76.57750842	19.14437710	25.35	<.0001
Location*C_S	1	14.53363636	14.53363636	19.24	<.0001
F_NF*C_S	1	0.01946128	0.01946128	0.03	0.8725

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 17. Model of total number of threecornered alfalfa hopper per sweep-net sample, 2019, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	338.740862	13.028495	4.45	<.0001
Error	723	2118.727138	2.930466		
Corrected Total	749	2457.468000			

R-Square	Coeff Var	Root MSE	Threecornered_Alfalfa_Hopper Mean
0.137841	152.3008	1.711860	1.124000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	3.5363333	3.5363333	1.21	0.2723
Cover	4	6.2080000	1.5520000	0.53	0.7140
F_NF ¹	1	0.1080000	0.1080000	0.04	0.8478
C_S ²	1	319.8801515	319.8801515	109.16	<.0001
Cover*F_NF ³	4	1.1786667	0.2946667	0.10	0.9823
Location*Cover	4	4.7820000	1.1955000	0.41	0.8030
Location*F_NF	1	0.0270000	0.0270000	0.01	0.9236
Location*Cover*F_NF	4	1.0780000	0.2695000	0.09	0.9850
Cover*C_S	4	1.6773401	0.4193350	0.14	0.9660
Location*C_S	1	0.2548485	0.2548485	0.09	0.7682
F_NF*C_S	1	0.0105219	0.0105219	0.00	0.9522

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 18. Influence of cover crop management practice on number of pest and beneficial arthropods at two locations in Tennessee, 2019 and 2020.

Year	Comparison of Cover Crop Management Practice	Average Total Pests in Sweeps		Average Total Beneficials in Sweeps		Average Total Pests in Beat-sheet		Average Total Beneficials in Beat-sheet		Average Slug Incidence	
		ETREC ¹	MTREC ¹	ETREC	MTREC	ETREC	MTREC	ETREC	MTREC	ETREC	MTREC
		Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)
2019	Traditional – Dual-use	0.425 ²	0.485	0.945	0.384	0.462	0.941	0.848	0.858	0.482	0.400
2020	Traditional – Dual-use	0.972	0.749	0.569	0.964	N/A	N/A	N/A	N/A	N/A	N/A

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

² P-values represent combined pre-termination cover crop data and post-planting soybean data, with the exception of beat-sheet data which were only collected after soybean planting. Analyzed at p=0.05, Tukey's HSD.

Table 19. Model of average total number of pest arthropods per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	3520.246553	135.394098	10.26	<.0001
Error	183	2415.934114	13.201826		
Corrected Total	209	5936.180667			

R-Square	Coeff Var	Root MSE	Average_Total_Pest Mean
0.593015	72.27855	3.633432	5.026984

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	427.282677	427.282677	32.37	<.0001
Cover	4	1752.918415	438.229604	33.19	<.0001
F_NF ¹	1	3.137043	3.137043	0.24	0.6265
C_S ²	1	221.261408	221.261408	16.76	<.0001
Cover*F_NF ³	4	5.997887	1.499472	0.11	0.9776
Location*Cover	4	284.345111	71.086278	5.38	0.0004
Location*F_NF	1	2.957700	2.957700	0.22	0.6365
Location*Cover*F_NF	4	12.958294	3.239574	0.25	0.9122
Cover*C_S	4	665.432753	166.358188	12.60	<.0001
Location*C_S	1	121.867221	121.867221	9.23	0.0027
F_NF*C_S	1	22.088044	22.088044	1.67	0.1975

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 20. Model of average total number of beneficial arthropods per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	326.4106294	12.5542550	7.16	<.0001
Error	183	320.9037085	1.7535722		
Corrected Total	209	647.3143379			

R-Square	Coeff Var	Root MSE	Average_Total_Beneficial Mean
0.504254	79.91015	1.324225	1.657143

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	0.0044094	0.0044094	0.00	0.9601
Cover	4	180.7640115	45.1910029	25.77	<.0001
F_NF ¹	1	1.5428571	1.5428571	0.88	0.3495
C_S ²	1	0.2039935	0.2039935	0.12	0.7334
Cover*F_NF ³	4	4.9439156	1.2359789	0.70	0.5896
Location*Cover	4	51.8945988	12.9736497	7.40	<.0001
Location*F_NF	1	1.3657859	1.3657859	0.78	0.3786
Location*Cover*F_NF	4	5.1999018	1.2999755	0.74	0.5650
Cover*C_S	4	51.9156936	12.9789234	7.40	<.0001
Location*C_S	1	28.5681997	28.5681997	16.29	<.0001
F_NF*C_S	1	0.0072624	0.0072624	0.00	0.9488

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

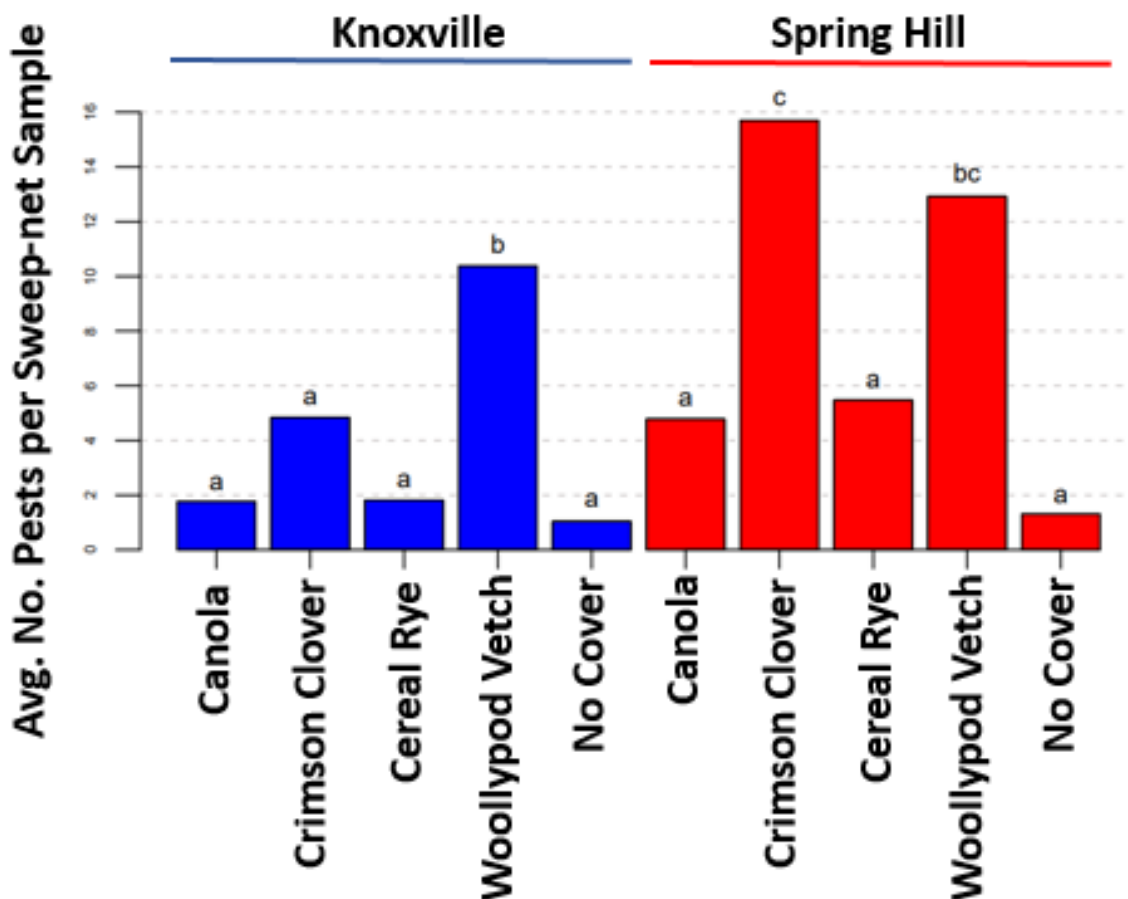


Figure 11. Influence of cover crop on average number of pest arthropods per sweep sample found in cover crops, 2020. Species with the same letter are not significantly different ($p>0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

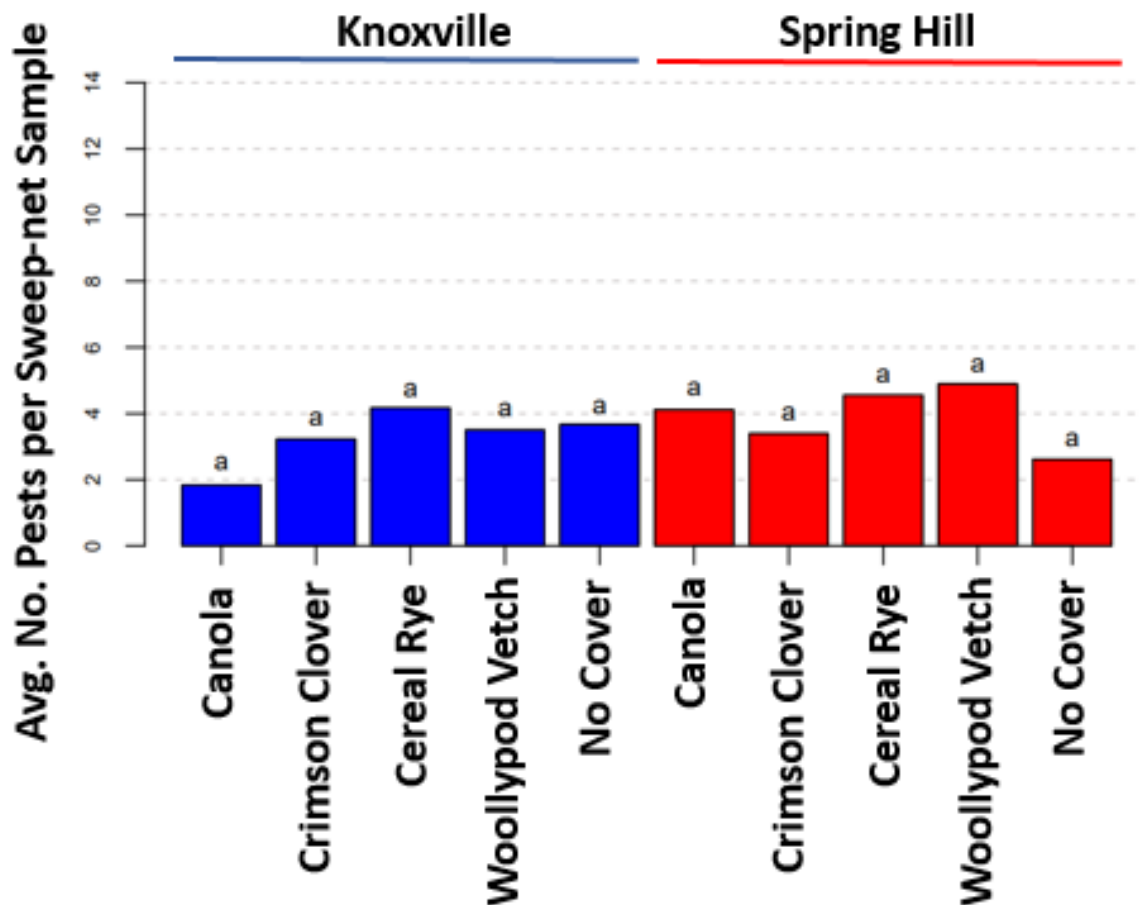


Figure 12. Influence of cover crop on average number of pest arthropods per sweep sample found in soybean, 2020. Species with the same letter are not significantly different ($p>0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

Table 21. Influence of cover crop species on number of pest and beneficial arthropods at two locations in Tennessee, 2020.

2020 Cover Crop Comparison	Average Total Pest in Sweeps		Average Total Beneficial in Sweeps	
	ETREC ¹	MTREC ¹	ETREC	MTREC
	Pr(> z)	Pr(> z)	Pr(> z)	Pr(> z)
Cereal Rye – Canola	0.957 ²	0.997	0.787	0.612
Crimson Clover – Canola	<u>0.026</u> ³	<u>< 0.001</u>	0.108	0.429
No Cover Crop – Canola	1.000	0.523	0.973	0.198
Woollypod Vetch - Canola	<u><0.001</u>	<u>0.011</u>	<u><0.001</u>	0.814
Crimson Clover – Cereal Rye	0.158	<u>0.002</u>	0.698	0.735
No Cover Crop – Cereal Rye	0.934	0.313	0.403	0.451
Woollypod Vetch – Cereal Rye	<u><0.001</u>	<u>0.032</u>	<u><0.001</u>	0.974
No Cover Crop – Crimson Clover	<u>0.019</u>	<u>< 0.001</u>	<u>0.020</u>	0.992
Woollypod Vetch – Crimson Clover	<u><0.001</u>	0.939	<u><0.001</u>	0.972
Woollypod Vetch – No Cover Crop	<u><0.001</u>	<u>< 0.001</u>	<u><0.001</u>	0.823

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

² P-values represent combined pre-termination cover crop data and post-planting soybean data.

³Bold text indicates significant difference between cover crop species (p<0.05); Tukey's HSD.

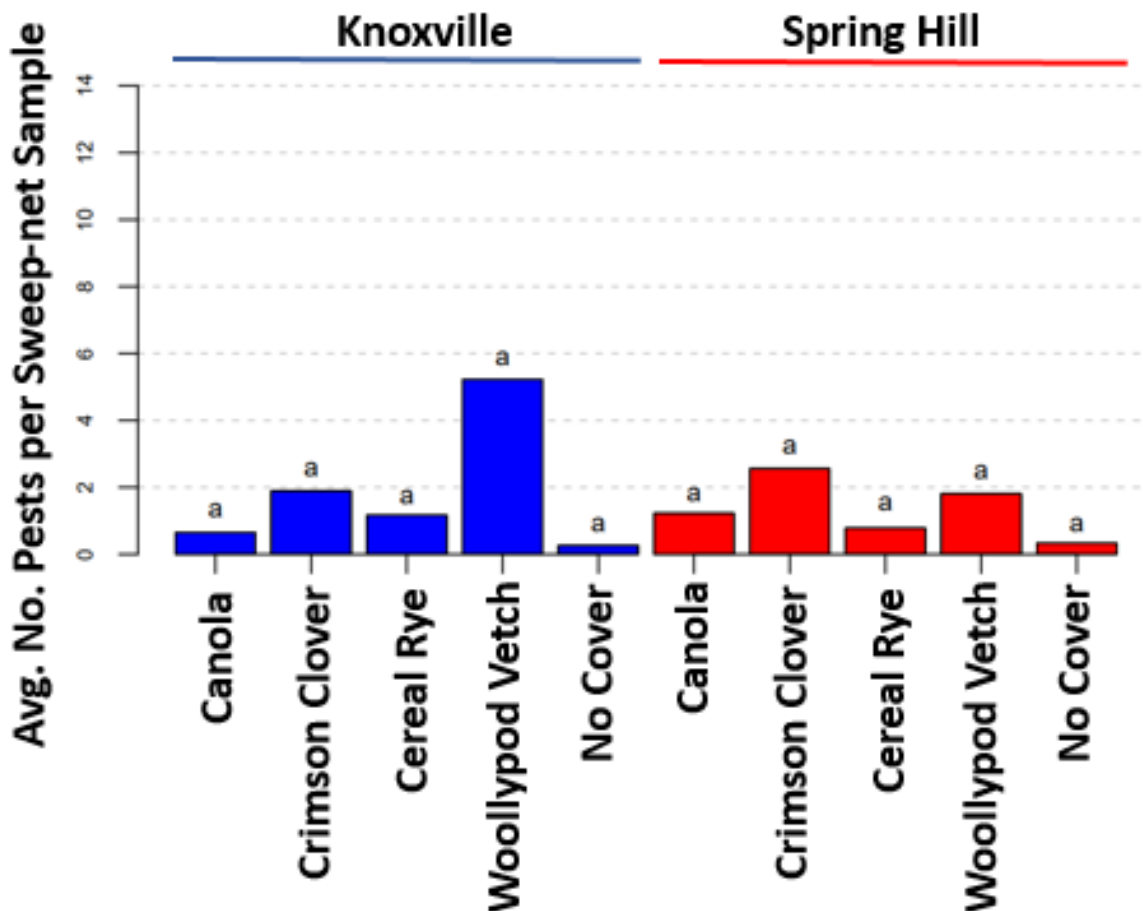


Figure 13. Influence of cover crop on average number of beneficial arthropods per sweep sample found in cover crops, 2020. Species with the same letter are not significantly different ($p > 0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

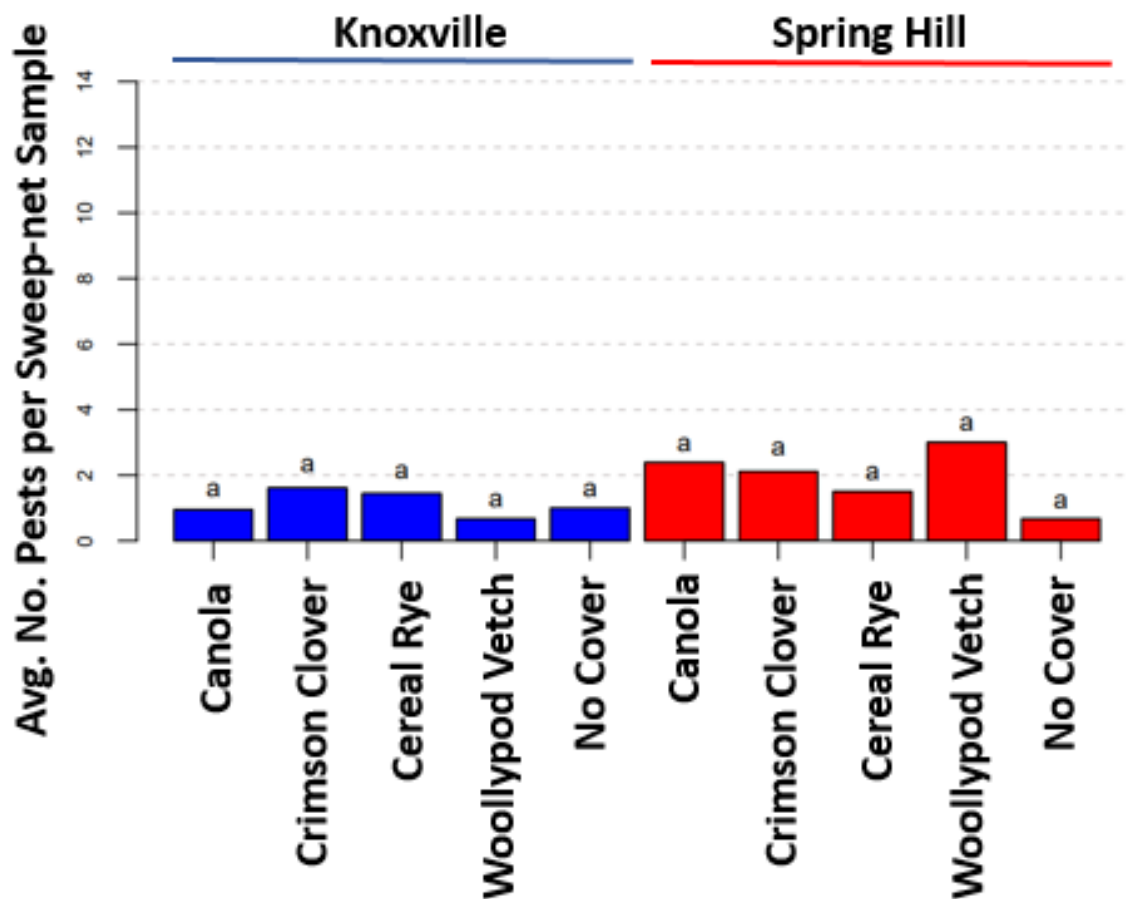


Figure 14. Influence of cover crop on average number of beneficial arthropods per sweep sample found in soybean, 2020. Species with the same letter are not significantly different ($p > 0.05$) (Tukey's HSD). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

Table 22. Model of total number of Aphididae per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	10137.88950	389.91883	6.22	<.0001
Error	183	11464.56765	62.64791		
Corrected Total	209	21602.45714			

R-Square	Coeff Var	Root MSE	Aphididae Mean
0.469293	130.0594	7.915043	6.085714

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	199.476587	199.476587	3.18	0.0760
Cover	4	3473.314286	868.328571	13.86	<.0001
F_NF ¹	1	8.400000	8.400000	0.13	0.7147
C_S ²	1	3213.925654	3213.925654	51.30	<.0001
Cover*F_NF ³	4	9.790476	2.447619	0.04	0.9971
Location*Cover	4	1681.291270	420.322817	6.71	<.0001
Location*F_NF	1	2.352778	2.352778	0.04	0.8466
Location*Cover*F_NF	4	82.915079	20.728770	0.33	0.8570
Cover*C_S	4	1316.919935	329.229984	5.26	0.0005
Location*C_S	1	146.699346	146.699346	2.34	0.1277
F_NF*C_S	1	2.804085	2.804085	0.04	0.8327

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 23. Model of total number of Curculionidae per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	668.571382	25.714284	3.84	<.0001
Error	183	1225.523856	6.696852		
Corrected Total	209	1894.095238			

R-Square	Coeff Var	Root MSE	Curculionidae Mean
0.352977	209.0168	2.587828	1.238095

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	71.3396825	71.3396825	10.65	0.0013
Cover	4	237.5238095	59.3809524	8.87	<.0001
F_NF ¹	1	2.3047619	2.3047619	0.34	0.5582
C_S ²	1	140.7163399	140.7163399	21.01	<.0001
Cover*F_NF ³	4	11.3142857	2.8285714	0.42	0.7924
Location*Cover	4	54.4817460	13.6204365	2.03	0.0915
Location*F_NF	1	1.4285714	1.4285714	0.21	0.6447
Location*Cover*F_NF	4	5.3134921	1.3283730	0.20	0.9390
Cover*C_S	4	109.1120915	27.2780229	4.07	0.0035
Location*C_S	1	33.8836601	33.8836601	5.06	0.0257
F_NF*C_S	1	1.1529412	1.1529412	0.17	0.6787

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 24. Model of total number of Chrysomelidae per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	7942.21303	305.46973	12.89	<.0001
Error	183	4337.41078	23.70170		
Corrected Total	209	12279.62381			

R-Square	Coeff Var	Root MSE	Chrysomelidae Mean
0.646780	124.2251	4.868439	3.919048

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	835.476587	835.476587	35.25	<.0001
Cover	4	3223.171429	805.792857	34.00	<.0001
F_NF ¹	1	21.376190	21.376190	0.90	0.3435
C_S ²	1	394.086438	394.086438	16.63	<.0001
Cover*F_NF ³	4	78.980952	19.745238	0.83	0.5057
Location*Cover	4	1023.434127	255.858532	10.79	<.0001
Location*F_NF	1	33.143254	33.143254	1.40	0.2385
Location*Cover*F_NF	4	13.791270	3.447817	0.15	0.9648
Cover*C_S	4	1865.072876	466.268219	19.67	<.0001
Location*C_S	1	384.005229	384.005229	16.20	<.0001
F_NF*C_S	1	69.674673	69.674673	2.94	0.0881

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 25. Model of total number of Cicadellidae per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	576.523483	22.173980	7.51	<.0001
Error	183	540.433660	2.953189		
Corrected Total	209	1116.957143			

R-Square	Coeff Var	Root MSE	Cicadellidae Mean
0.516155	121.5090	1.718485	1.414286

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	2.4765873	2.4765873	0.84	0.3610
Cover	4	58.9809524	14.7452381	4.99	0.0008
F_NF ¹	1	0.8047619	0.8047619	0.27	0.6023
C_S ²	1	344.9687908	344.9687908	116.81	<.0001
Cover*F_NF ³	4	36.3142857	9.0785714	3.07	0.0176
Location*Cover	4	11.6246032	2.9061508	0.98	0.4175
Location*F_NF	1	0.0480159	0.0480159	0.02	0.8987
Location*Cover*F_NF	4	11.5134921	2.8783730	0.97	0.4227
Cover*C_S	4	86.6218954	21.6554739	7.33	<.0001
Location*C_S	1	23.1228758	23.1228758	7.83	0.0057
F_NF*C_S	1	0.0472222	0.0472222	0.02	0.8995

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 26. Model of total number of Apidoidea per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	67.3819328	2.5916128	3.89	<.0001
Error	183	121.9323529	0.6662970		
Corrected Total	209	189.3142857			

R-Square	Coeff Var	Root MSE	Apidoidea Mean
0.355926	238.0788	0.816270	0.342857

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	2.86706349	2.86706349	4.30	0.0394
Cover	4	22.98095238	5.74523810	8.62	<.0001
F_NF ¹	1	1.21904762	1.21904762	1.83	0.1778
C_S ²	1	5.00408497	5.00408497	7.51	0.0067
Cover*F_NF ³	4	1.30476190	0.32619048	0.49	0.7434
Location*Cover	4	5.34126984	1.33531746	2.00	0.0958
Location*F_NF	1	2.86706349	2.86706349	4.30	0.0394
Location*Cover*F_NF	4	9.81746032	2.45436508	3.68	0.0065
Cover*C_S	4	10.55228758	2.63807190	3.96	0.0042
Location*C_S	1	5.27091503	5.27091503	7.91	0.0055
F_NF*C_S	1	0.15702614	0.15702614	0.24	0.6279

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 27. Model of total number of big-eyed bug per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	99.0592904	3.8099727	2.61	0.0001
Error	183	267.2692810	1.4604879		
Corrected Total	209	366.3285714			

R-Square	Coeff Var	Root MSE	Big_Eyed_Bug Mean
0.270411	179.9903	1.208506	0.671429

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	3.58134921	3.58134921	2.45	0.1191
Cover	4	41.20952381	10.30238095	7.05	<.0001
F_NF ¹	1	0.00476190	0.00476190	0.00	0.9545
C_S ²	1	13.08643791	13.08643791	8.96	0.0031
Cover*F_NF ³	4	3.78095238	0.94523810	0.65	0.6295
Location*Cover	4	5.10714286	1.27678571	0.87	0.4805
Location*F_NF	1	0.11468254	0.11468254	0.08	0.7796
Location*Cover*F_NF	4	9.94682540	2.48670635	1.70	0.1513
Cover*C_S	4	20.90294118	5.22573529	3.58	0.0078
Location*C_S	1	0.14411765	0.14411765	0.10	0.7538
F_NF*C_S	1	1.18055556	1.18055556	0.81	0.3698

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 28. Model of total number of Coccinellidae per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	139.1211951	5.3508152	4.80	<.0001
Error	183	204.1359477	1.1154970		
Corrected Total	209	343.2571429			

R-Square	Coeff Var	Root MSE	Coccinellidae Mean
0.405297	154.0249	1.056171	0.685714

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	7.55714286	7.55714286	6.77	0.0100
Cover	4	65.97142857	16.49285714	14.79	<.0001
F_NF ¹	1	0.93333333	0.93333333	0.84	0.3615
C_S ²	1	19.11176471	19.11176471	17.13	<.0001
Cover*F_NF ³	4	0.82857143	0.20714286	0.19	0.9456
Location*Cover	4	17.17301587	4.29325397	3.85	0.0050
Location*F_NF	1	0.31111111	0.31111111	0.28	0.5981
Location*Cover*F_NF	4	0.81587302	0.20396825	0.18	0.9471
Cover*C_S	4	25.71830065	6.42957516	5.76	0.0002
Location*C_S	1	0.18823529	0.18823529	0.17	0.6817
F_NF*C_S	1	0.51241830	0.51241830	0.46	0.4988

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 29. Model of total number of Syrphidae per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	1463.838235	56.301471	12.58	<.0001
Error	183	819.061765	4.475747		
Corrected Total	209	2282.900000			

R-Square	Coeff Var	Root MSE	Syrphidae Mean
0.641219	192.3269	2.115596	1.100000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	103.6194444	103.6194444	23.15	<.0001
Cover	4	655.0190476	163.7547619	36.59	<.0001
F_NF ¹	1	8.0047619	8.0047619	1.79	0.1828
C_S ²	1	84.4707516	84.4707516	18.87	<.0001
Cover*F_NF ³	4	20.8285714	5.2071429	1.16	0.3285
Location*Cover	4	287.8865079	71.9716270	16.08	<.0001
Location*F_NF	1	10.8035714	10.8035714	2.41	0.1220
Location*Cover*F_NF	4	38.8769841	9.7192460	2.17	0.0739
Cover*C_S	4	216.0709150	54.0177288	12.07	<.0001
Location*C_S	1	36.0209150	36.0209150	8.05	0.0051
F_NF*C_S	1	2.2367647	2.2367647	0.50	0.4805

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 30. Model of total number of threecornered alfalfa hoppers per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	229.9660131	8.8448467	7.00	<.0001
Error	183	231.1006536	1.2628451		
Corrected Total	209	461.0666667			

R-Square	Coeff Var	Root MSE	Threecornered_Alfalfa_Hopper Mean
0.498770	153.2405	1.123764	0.733333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	7.7777778	7.7777778	6.16	0.0140
Cover	4	1.9714286	0.4928571	0.39	0.8154
F_NF ¹	1	0.3047619	0.3047619	0.24	0.6238
C_S ²	1	163.3986928	163.3986928	129.39	<.0001
Cover*F_NF ³	4	6.5047619	1.6261905	1.29	0.2765
Location*Cover	4	17.5396825	4.3849206	3.47	0.0092
Location*F_NF	1	0.4063492	0.4063492	0.32	0.5712
Location*Cover*F_NF	4	1.0063492	0.2515873	0.20	0.9385
Cover*C_S	4	23.8888889	5.9722222	4.73	0.0012
Location*C_S	1	6.2235294	6.2235294	4.93	0.0277
F_NF*C_S	1	0.9437908	0.9437908	0.75	0.3884

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 31. Model of total number of minute pirate bugs per sweep-net sample, 2020, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	102.4034080	3.9385926	6.00	<.0001
Error	183	120.1918301	0.6567860		
Corrected Total	209	222.5952381			

R-Square	Coeff Var	Root MSE	Minute_Pirate_Bug Mean
0.460043	309.4344	0.810423	0.261905

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	8.92857143	8.92857143	13.59	0.0003
Cover	4	8.04761905	2.01190476	3.06	0.0179
F_NF ¹	1	0.80476190	0.80476190	1.23	0.2698
C_S ²	1	33.08823529	33.08823529	50.38	<.0001
Cover*F_NF ³	4	1.55238095	0.38809524	0.59	0.6696
Location*Cover	4	11.48015873	2.87003968	4.37	0.0021
Location*F_NF	1	1.07301587	1.07301587	1.63	0.2028
Location*Cover*F_NF	4	3.54206349	0.88551587	1.35	0.2538
Cover*C_S	4	17.70751634	4.42687908	6.74	<.0001
Location*C_S	1	14.41176471	14.41176471	21.94	<.0001
F_NF*C_S	1	1.76732026	1.76732026	2.69	0.1026

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.



Figure 15. Preparation of slug traps for placement in the field.

Table 32. Model of average total number of slugs collected in traps, 2019, ANOVA GLM ($p \leq 0.05$).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	38.0045527	1.4617136	2.58	<.0001
Error	393	222.5189923	0.5662061		
Corrected Total	419	260.5235450			

R-Square	Coeff Var	Root MSE	Average_Total_Slugs Mean
0.145878	304.8579	0.752467	0.246825

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Location	1	13.86351411	13.86351411	24.48	<.0001
Cover	4	1.60423280	0.40105820	0.71	0.5866
F_NF ¹	1	0.19285714	0.19285714	0.34	0.5598
C_S ²	1	10.59283510	10.59283510	18.71	<.0001
Cover*F_NF ³	4	0.64444444	0.16111111	0.28	0.8880
Location*Cover	4	0.72323633	0.18080908	0.32	0.8650
Location*F_NF	1	0.33353175	0.33353175	0.59	0.4432
Location*Cover*F_NF	4	0.72500000	0.18125000	0.32	0.8645
Location*C_S	1	8.04571429	8.04571429	14.21	0.0002
Cover*C_S	4	0.96964486	0.24241122	0.43	0.7883
F_NF*C_S	1	0.30954185	0.30954185	0.55	0.4601

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

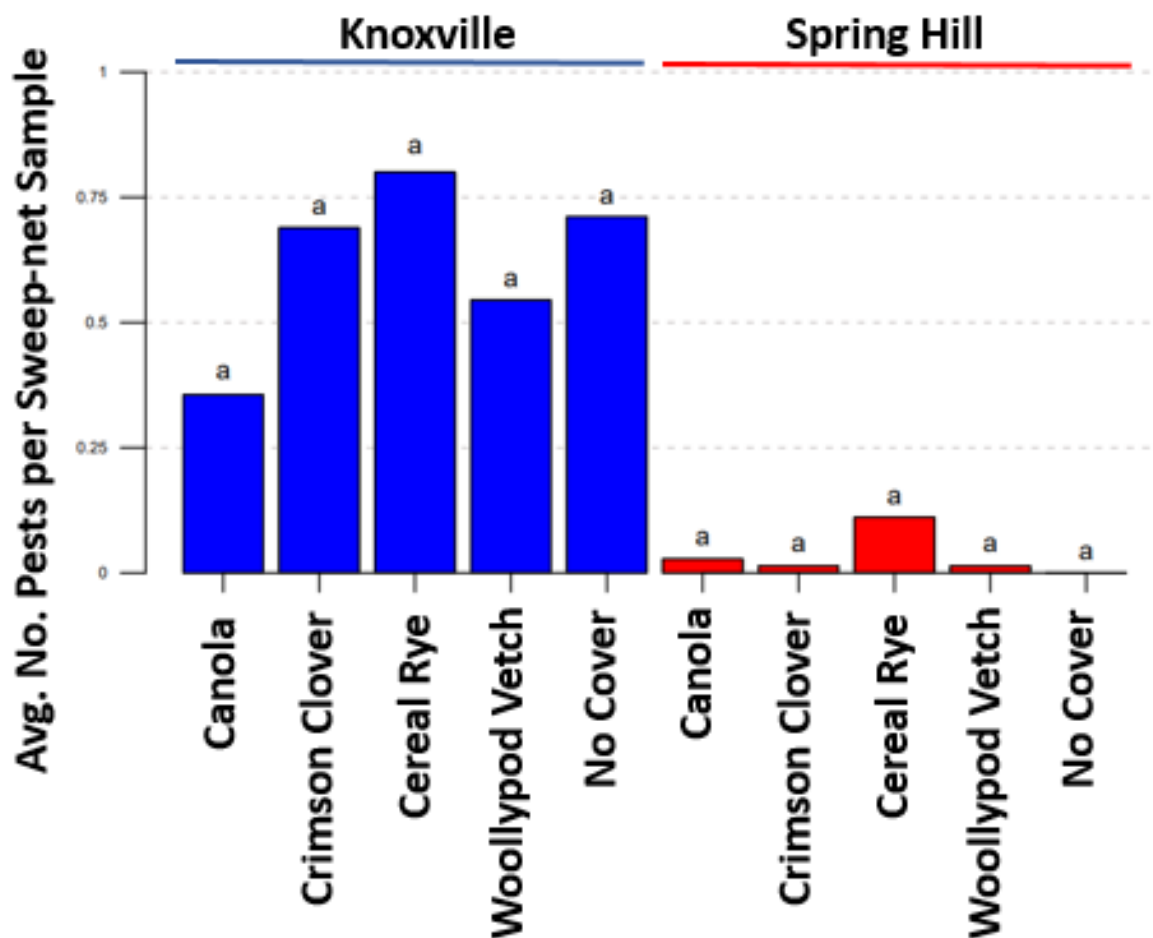


Figure 16. Average number of slugs by cover crop found in cover crops, 2019. Species with the same letter not significantly different (Tukey's HSD) ($p=0.05$). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

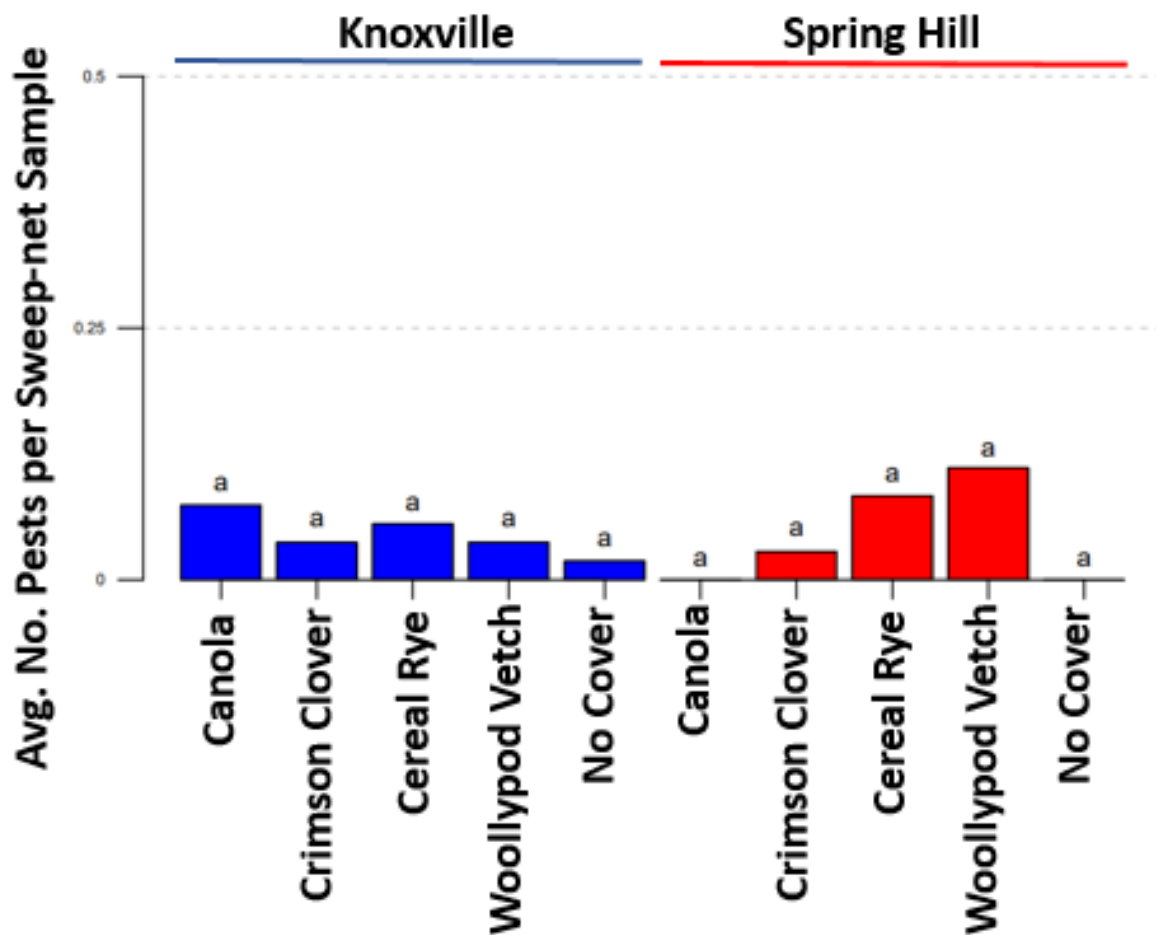


Figure 17. Average number of slugs by cover crop found in soybean, 2019. Species with the same letter not significantly different (Tukey's HSD) ($p=0.05$). Bars shaded in blue represent data from the Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN (ETREC). Bars shaded in red represent data from the Middle Tennessee AgResearch and Education Center in Spring Hill, TN (MTREC).

Table 33. Model of average total number of slugs per trap at Spring Hill, 2019, ANOVA GLM ($p \leq 0.05$).

Location=MTREC					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	0.64197531	0.03378817	1.74	0.0349
Error	160	3.11111111	0.01944444		
Corrected Total	179	3.75308642			

R-Square	Coeff Var	Root MSE	Average_Total_Slugs Mean
0.171053	376.4970	0.139443	0.037037

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cover	4	0.22839506	0.05709877	2.94	0.0224
F_NF ¹	1	0.02222222	0.02222222	1.14	0.2867
C_S ²	1	0.00493827	0.00493827	0.25	0.6150
Cover*F_NF ³	4	0.07037037	0.01759259	0.90	0.4627
Cover*C_S	4	0.08456790	0.02114198	1.09	0.3647
F_NF*C_S	1	0.10000000	0.10000000	5.14	0.0247
Cover*F_NF*C_S	4	0.13148148	0.03287037	1.69	0.1547

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 34. Model of average total number of slugs per trap at Knoxville, 2019, ANOVA GLM ($p \leq 0.05$).

Location=ETREC					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	25.0304012	1.3173895	1.33	0.1661
Error	220	217.8765432	0.9903479		
Corrected Total	239	242.9069445			

R-Square	Coeff Var	Root MSE	Average_Total_Slugs Mean
0.103045	246.2257	0.995162	0.404167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cover	4	2.09907407	0.52476852	0.53	0.7139
F_NF ¹	1	0.50416667	0.50416667	0.51	0.4763
C_S ²	1	18.63361111	18.63361111	18.82	<.0001
Cover*F_NF ³	4	1.29907407	0.32476852	0.33	0.8590
Cover*C_S	4	1.56561728	0.39140432	0.40	0.8120
F_NF*C_S	1	0.21262346	0.21262346	0.21	0.6436
Cover*F_NF*C_S	4	0.71623457	0.17905864	0.18	0.9482

¹Management practices: F=Dual-use cover cropping and NF=Traditional cover cropping.

²C=data collected before cover crop termination and S=data collected after soybean planting.

³The asterisk (*) denotes analysis of interaction between variables.

Table 35. Cover crop biomass (kg/ha) at two locations in Tennessee, 2019 and 2020.

Year	Location	Cover Crop	Replication 1		Replication 2		Replication 3	
			T ²	D ²	T	D	T	D
2019	ETREC ¹	Canola	914.932	505.904	1248.614	968.752	775.002	290.626
	ETREC	Crimson Clover	1367.017	1227.086	1722.226	1162.502	2185.074	2421.880
	ETREC	Cereal Rye	1227.086	1130.211	1959.032	1022.571	1550.003	1991.323
	ETREC	Woodypod Vetch	1065.627	1302.433	2970.839	1367.017	4240.981	2357.296
	ETREC	No Cover	150.695	75.347	247.570	570.487	204.514	365.973
	MTREC ¹	Canola	2680.214	7750.015	7986.821	7222.584	5801.543	N/A
	MTREC	Crimson Clover	5984.734	4068.758	7911.474	6393.763	5091.748	4262.509
	MTREC	Cereal Rye	6253.832	7179.528	5317.372	5102.094	4972.927	4456.259
	MTREC	Woodypod Vetch	2960.075	3788.896	1636.114	2841.672	3358.340	2680.214
	MTREC	No Cover	990.280	N/A ³	2518.755	678.126	35.521	613.543
2020	ETREC	Canola	222.222	555.556	133.333	72.2222	333.333	55.556
	ETREC	Crimson Clover	3555.556	2777.778	2111.111	3333.333	2333.333	2777.778
	ETREC	Cereal Rye	2111.111	2333.333	1111.111	1888.889	2555.556	3333.333
	ETREC	Woodypod Vetch	7000.000	7000.000	4444.444	5333.333	6111.111	4555.556
	ETREC	No Cover	22.222	55.556	N/A	55.556	111.111	27.778
	MTREC	Canola	111.111	333.333	888.889	1111.111	333.333	222.222
	MTREC	Crimson Clover	5777.778	3111.111	3222.222	4888.889	LOST ⁴	4888.889
	MTREC	Cereal Rye	2555.556	3888.889	3222.222	3222.222	3333.333	3222.222
	MTREC	Woodypod Vetch	3666.667	4777.778	3000.000	3777.778	4777.778	5000.000
	MTREC	No Cover	111.111	222.222	222.222	444.444	666.667	222.222

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

²Management practices were T=Traditional cover cropping and D=Dual-use cover cropping.

³N/A denotes insufficient biomass present in the plot for harvest.

⁴This plot was accidentally terminated prematurely.

Table 36. Pearson's correlation coefficients (r) between arthropods/slugs and cover crop biomass/soybean yield at two locations in Tennessee, 2019 and 2020.

Correlation	2019		2020	
	ETREC ¹	MTREC ¹	ETREC	MTREC
Cover Crop Biomass – Soybean Yield	0.250 ²	-0.204	N/A	N/A
Average Total Pests in Sweeps – Cover Crop Biomass	0.095	0.115	0.641	0.461
Average Total Beneficials in Sweeps – Cover Crop Biomass	-0.069	-0.042	0.646	0.233
Average Total Pests in Beat-sheet – Cover Crop Biomass	0.016	0.084	N/A	N/A
Average Total Beneficials in Beat-sheet – Cover Crop Biomass	-0.073	0.056	N/A	N/A
Average Slug Incidence – Cover Crop Biomass	-0.001	0.018	N/A	N/A
Average Total Pests in Sweeps – Soybean Yield	0.029	0.167	N/A	N/A
Average Total Beneficials in Sweeps – Soybean Yield	0.016	0.012	N/A	N/A
Average Total Pests in Beat-sheet – Soybean Yield	0.059	-0.064	N/A	N/A
Average Total Beneficials in Beat-sheet – Soybean Yield	0.025	0.060	N/A	N/A
Average Slug Incidence – Soybean Yield	-0.010	0.021	N/A	N/A

¹ETREC = Plant Sciences Unit of the East Tennessee AgResearch and Education Center in Knoxville, TN; MTREC = Middle Tennessee AgResearch and Education Center in Spring Hill, TN.

² Values close to ± 1 have a high degree of correlation.

VITA

Matthew Lee Longmire was born March 3, 1997, at the University of Tennessee Medical Center in Knoxville, TN, to his parents Charles and Sandra Longmire. He grew up in Anderson County, Tennessee on his family's farm. Since he was little, he was always fascinated with the world of insects. In elementary school, he would check out books from the library on insects and began his insect collection, which he maintains to this day.

In May of 2015, he graduated third in his class from Anderson County High School in Clinton, TN. After high school, he attended the University of Tennessee in Knoxville Tennessee, where he obtained a Bachelor of Science degree in Biological Sciences with a concentration in Ecology and Evolutionary Biology, and a minor in Entomology and Plant Pathology in May of 2018. In August of 2018, Matthew began a Master of Science program in the laboratory of Dr. Jerome Grant in the Department of Entomology and Plant Pathology at the University of Tennessee, Knoxville and concluded his program in August of 2020. Matthew is a member of the Tennessee Entomological Society and the Entomological Society of America.