ABSTRACT

Title of Thesis:	THE EFFECT OF BARLEY COVER CROP RESIDUE AND HERBICIDE MANAGEMENT ON THE ARTHROPOD COMMUNITY IN NO-TILL SOYBEANS
	Armando Rosario-Lebron Masters of Science 2016
Thesis Directed By:	Associate Professor Cerruti RR Hooks, Department of Entomology

Cover cropping has long been used as a method of reducing soil erosion, increasing soil quality and suppressing weeds. However, effects of cover crops in local farming systems are varied and can be affected by timing and method of cover crop termination. We conducted two field studies each in Upper Marlboro and Beltsville, Maryland between 2013 and 2014. The study consisted of three cover crop and one Fallow(F) treatments. Cover crop treatments were Early-Kill (EK) and Late-Kill in which the cover crop was killed with a post-emergent herbicide in late April and May, respectively; and flail mow (FM), in which a flail mower was used to terminate the cover crop in late May. In 2013 and 2014, plant sucking insects were consistently more numerous in EK than LK treatment. Our findings suggest chemical

and mechanical termination on cover crops produce similar results on arthropod populations.

THE EFFECT OF BARLEY COVER CROP RESIDUE AND HERBICIDE MANAGEMENT ON THE ARTHROPOD COMMUNITY IN NO-TILL SOYBEANS

by

Armando Rosario-Lebron

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Masters in Entomology
2016

Advisory Committee:
Professor Cerruti RR Hooks, Chair
Professor Pedro Barbosa
Professor Paula Shrewsbury

Table of Contents

List of Tables

List of Figures

List of Abbreviations

i. FM refers to the Flail Mowed treatment.

ii. EK refers to Early Kill treatment.

iii. LK refers to the Late Kill treatment.

iv. F refers to the Fallow; no cover crop treatment

Introduction

Producers typically plant grass or grass-legume cover crop mixtures to provide ground coverage during periods when cash crops are not in season (Price et al. 2009). Cover cropping has long been used to reduce soil erosion in agricultural fields, and to retain post-harvest residual nutrients or add nutrient(s) by fixing atmospheric nitrogen (Unger and Vigil 1998). More recently, cover cropping has been advocated nationwide for its ability to maintain soil health. Cover cropping may also have profound effects on organisms living aboveground. Cover cropping practices are diverse and vary according to land managers' goals. For example, cover crops can be grown with cash crops as living mulches that exist throughout the cash crop growth cycle (Liebman and Dyck 1993). Cover crops can also be grown as naturally senescing companion plants or dying mulch that are timed to die off at an ideal period in the growth of the cash crop. However, most cover crops are planted in the fall and terminated chemically prior to cash target crop planting. This is done primarily to reduce competition for resources with the main crop (Brainard and Bellinder 2004). Termination of the cover crop results in residues from decaying plant material that remains on the soil surface. These surface residues vary in dry biomass based on the total biomass that accumulates just prior to cover crop termination (Morton et al. 2006) and the length of time they remain on the soil surface.

Variations in accumulated biomass are assumed to affect populations of arthropods within agricultural systems by changing the structure and complexity of the resulting habitat (Bryant et al. 2014). Increases in biomass are expected to increase habitat complexity and increase the heterogeneity of the resulting agroecosystem. It is therefore logical to predict that the effects of cover crop residue biomass will cause an increase in species richness. The effects of increasing habitat complexity on arthropod populations in agricultural systems through enhanced vegetation diversity have been well elucidated (Lawton and Strong 1981, Altieri 1999, Landis et al. 2000, Obermaier et al. 2008). In this work, agricultural complexity is defined according to Lawton and Strong (1981). Their description assumes habitats with less complexity, also called simple habitats, are defined as those with lower biomass and diversity of plant resources and architecture. Plant architecture is described as the height, heterogeneity and structural complexity of the plant. This work will consider the non-living ground coverage of the cover crop as part of its architectural complexity.

When a cover crop is terminated, the resulting residue enhances habitat complexity by covering the soil surface. The resulting cover is then expected to increase the complexity of the habitat through increased soil coverage (Mulvaney et al. 2011, Bryant et al. 2013, 2014). The amount of cover crop residue that remains on the soil surface as dry biomass can vary by species, method of termination and time allowed for growth of the cover crop prior to termination (Wortman et al. 2012, Mirsky et al. 2013). These changes in habitat complexity within agro-ecosystems can affect numerous species, amongst which natural enemies are of particular interest. Natural enemies may be attracted directly to refuges created when a cover crop is terminated or to alternative prey found within the refuge (Bottenberg et al. 1999, Bianchi et al. 2006, Bone et al. 2009, Kawashima and Jung 2010, Zhang et al. 2010, Gill et al. 2011, Dunbar et al. 2012, Bryant et al. 2014). These natural enemies can help prevent herbivores from reaching economical damaging levels.

Several studies have shown also that cover crops and how they are managed can influence herbivore populations in field crop plantings. Koch et al. (2012) compared effects of early and late terminated winter rye, *Secale cereal*, in soybean, *Glycine max*, to determine if foliar arthropod counts would be impacted by cover crop management practices. They found that the presence of rye cover crop residues reduced potato leaf hopper, *Empoasca fabae*, densities compared to the non-cover crop treatment. Smith et al. (1988) observed reductions in potato leafhopper, *Empoasca fabae*, and increases in bean leaf beetle, *Cerotoma trifucata*, and Japanese beetle, *Popilla japonica*, numbers in no-till soybean that was planted into an early terminated versus late terminated rye cover crop. Further, there were significantly lower numbers of soybean aphids, *Aphis glycines*, in soybeans planted after a rye cover crop compared to soybeans planted in fallow soil. Similarly, decreased number of herbivorous insects have been found in cotton, soybean and corn when residues of rye, oat (*Avena sativa*) and wheat (*Triticum sp.*) remained on the soil surface (Tillman et al. 2004, Olson et al. 2006, Obrycki et al. 2009, Reeves et al. 2010, Aulakh et al. 2012).

Alteration in cover crop management practices have been shown to impact communities of arthropods within specialty crop systems as well. Bryant et al. (2014) demonstrated that variation in oat cover crop in terms of timing of termination using either a pre-emergent herbicide alone or a pre-emergent and post emergent herbicide mixture affected foliar arthropods present in cabbage, *Brassica oleracea*. Oat residues were highest in late season terminated cover crops, which correlated with increased densities of natural enemies. Treatments that received pre-emergent herbicides only and were terminated late season had fewer herbivores and higher densities of predators compared to those in treatments that were mowed, terminated early or left fallow.

Natural enemies of crop pests may also be influenced by cover crop management practices. Lundgren and Fergen (2011) found that autumn planted slender wheatgrass, *Elymus trachycaulus*, increased subterranean predator diversity in the following maize, *Zea mays*, crop compared to maize planted in fallow soil.

Navntoft et al. (2016) showed a positive correlation of spider density to the amount of above ground residue generated by harrowing the soil. Habitats harrowed twice in a season contained more above ground residues and spiders throughout the season compared to treatment habitats that were harrowed four times. Spiders have been shown also to favor soybean systems where weed density, living or dead allows for the creation of attachment points and the potential for alternate prey (Balfour and Rypstra 1998). Given the precedent for spider densities to increase under high cover crop residues those are expected to be found in greater number in management systems that provide the greatest cover crop biomass. Carabid beetles may be influenced also by cover crop practices, however, existing literature focuses mainly on the effect of different tillage practices on their densities. Jabbour et al. (2015) found no effect of cover crop biomass density on carabid predator numbers in soybean planted with a cereal cover crop on a two-year rotation with corn and soybean. Blubaugh and Kaplan (2015) found carabid predator densities unchanged by the presence of rye and vetch, *Secale cereale L.,and Vicia villosa* cover crop residue in conventionally managed soybean system. Findings from these studies supports the supposition that alteration in cover crop management practices can impact communities of arthropods within subsequent cash crops.

In Maryland, soybeans are planted on roughly 206,000 hectares of land, with an annual net worth of 228 million US Dollars in 2014, alone (USDA 2015). Several economically important arthropod herbivores found in soybean plantings are influenced by cover crop management practices. These include the soybean aphid, *Aphis glycines* (Woltz et al. 2012, Bahlai et al. 2013), three cornered leaf hopper, *Spissistilus festinus* (Koch et al. 2012), potato leafhopper, *Empoasca fabae* (Buckelew et al. 2000, Koch et al. 2012), various species of grasshoppers (Othoptera: *Acrididae)* (Andow 1990), stink bugs (Hemiptera: Pentatomidae) (Tillman et al. 2004), two spotted spider mite (Peachey et al. 2002, Langellotto and Denno 2004), bean leaf beetle, *Cerotoma trifucata*, and Japanese beetle, *Popilla japonica* (Smith et al. 1988). These studies have shown that herbivore responses to the presence of cover crops in soybean habitats may be positive, negative or neutral.

The state of Maryland, through an incentive program aimed at protecting the Chesapeake Bay and its tributaries, provides cost share money to farmers to plant cover crops during the non-crop season. This program has resulted in record amounts of land acreage planted with cover crops in Maryland. There is indication from the state government that these subsidies have been growing and will continue to increase ("Maryland Cover Crop Program" 2014). However, management practices, with respect to when and how cover crops are terminated, vary among producers. Variations in cover crop management techniques can affect the amount of cover crop residue that remains on the soil surface (Jackson and Harrison 2008, Wortman et al. 2012, Mirsky et al. 2013), which subsequently impacts habitat complexity (Bryant et al. 2014). Variations in habitat complexity may alter the community composition of arthropods within soybean fields. In Maryland, farmers typically terminate their cover crop with a post emergent herbicide during early spring. In some instances, terminating the cover crop early may allow for increased soil temperatures and clear the schedule for other management practices later in the season. However, other producers may terminate their cover crop later in the season to allow for greater cover crop biomass accumulation. The choice of strategy is tied mainly to the cropping system used and schedule of the producer.

The objective of this study was to determine the impact of timing and method of cover crop termination on the arthropod community within soybean fields. Practices being evaluated were designed to mimic the most common cover cropping tactics practiced by Maryland and other Mid-Atlantic soybean producers. Barley, *Hordeum vulgare*, was chosen as the test cover crop, as it is inexpensive relative to other cereal cover crops, establishes quickly, and Maryland producers can receive grants through the Maryland Agricultural Water Quality Cost-Share (MACS) Program to plant it in fields that would otherwise be fallow during the non-cash crop season. The overall objective was to investigate how different cover crop termination practices impact the foliar arthropod community within no-till soybean plantings. Specific objectives were to compare the influence of chemically versus mechanically and early versus late season cover crop termination practices on the foliar arthropods, and to determine if terminated cover crop impact arthropod community within soybean.

Materials and Methods

Field experiments were conducted at the University of Maryland's Central Maryland Research and Education Center (Upper Marlboro, MD) and Beltsville Research and Education Center (Beltsville, MD). Studies were conducted during the 2013 and 2014 growing seasons. Study areas were previously farmed on a two-year rotation of corn and soybean in alternation. In 2013, the Beltsville study site was previously planted with grain sorghum, *Sorghum bicolor* as opposed to corn. Study areas were surrounded by production corn plantings, and the Beltsville study site was bordered by wooded areas on one side during each field trial. Soybeans were planted with a Great Plains no-till drill (model 1005) at ~411840 seeds/ha in 2013 and ~384384 seeds/ha in 2014. The experiment consisted of four treatments replicated four times. Each plot consisted of 16 and 68 rows of soybean in Beltsville and Upper Marlboro, respectively. Soybeans used during the study were LibertyLink® maturity group four variety Stine 42LD02 (Bayer Crop Sciences; DeWitt, AK, USA) planted at an inter-row spacing of 76 cm at Beltsville and 18 cm at Upper Marlboro. The initial protocol included planting the soybean at 76 cm row spacing at each site during both study years. However, the land manager mistakably planted the soybean at 18 cm spacing during 2013 so it was decided to maintain this spacing the following year. Each treatment plot measured 12 m x 10 m and was separated from other plots by 6 m of bare soil. In the fall, barley was planted into 12 plots at 135 kg/ha on 21 September 2012 at both locations**.** For the 2014 growing season, barley was planted on 24 September 2013 at the same rate as in 2012. In both study years, four plots were left fallow at each site as the non-cover crop or control treatment. The three cover crop treatments included: (1) Early kill (EK) - cover crop sprayed with post- and pre-emergent herbicides in mid-April (about one-month prior to planting soybean), (2) Late kill (LK) - cover crop sprayed with post- and pre- emergent herbicides on the day soybeans were planted, and (3) Flail mow (FM) - pre-emergent herbicide applied and cover crop mowed on the day soybeans were planted. The no-cover crop control treatment [fallow (F)] received the same spray protocol as the LK treatment.

Herbicides used were Gramaxone SL® (Syngenta Crop Protection LLC; Greensboro, NC, USA) as a post emergent herbicide at 1.17 L/ha and 2.34 L/ha at the Beltsville and Upper Marlboro locations each year and Authority First® (FMC Corporation, Agricultural Products Group; Philadelphia, PA, USA) applied at 329 ml/ha at all field locations as a pre-emergent herbicide. The post- and pre-emergent herbicides were applied on April 15 at the Beltsville site and April 16 in Upper Marlboro in 2013 and April 18 in both Beltsville and Upper Marlboro in 2014. In

2013, the FM treatment was sprayed with Authority® First on May 21 and 20 in Beltsville and Upper Marlboro, respectively and on May 27 in Beltsville and Upper Marlboro in 2014. A rescue application of Ignite ® (511 ml/ha) (Bayer Crop Sciences; DeWitt, AK, USA) was applied on July 11 2013 at the Beltsville location. The soybean was planted on May 21 and May 20 in Beltsville and Upper Marlboro, respectively in 2013 and May 27 in both Beltsville and Upper Marlboro in 2014.

Foliar sampling of pests and beneficial arthropods

Relative populations of arthropods on soybean foliage were estimated by sampling weekly with the use of a 38.1 cm-diameter canvas sweep net. A collected sweep sample consisted of 20 sweeps down and across two haphazardly chosen interior rows (~11 m total distance). In 2013, sampling began when soybean was in the V2 stage, approximately one month after planting. In 2014, sampling began immediately after emergence in the VE stage. Sampling was conducted weekly between the hours of 8:00 am and 12:00 pm and was discontinued at early senescence or roughly the R6 stage.

In 2013, a total of eight samples were collected in Upper Marlboro from July 10 to August 30, and eight samples were collected in Beltsville from July 10 to August 28. In 2014, a total of 14 samples were collected in Upper Marlboro from June 4 to September 10, and 15 samples were collected in Beltsville from June 3 to September 16. Arthropods were transferred into plastic storage bags, sealed and temporarily stored on ice in a portable cooler while in the field. They were then transported to the laboratory and stored in a freezer for later species identification and counting. Arthropod samples in bags were sorted on white trays under 100x magnification and micro-parasitoid wasps were identified to the family level and placed in 85% EtOH for storage. Arthropods were grouped into six functional feeding guilds. These feeding guilds consisted of insect predators [chewing predators (CP) and sucking predators (SP)], insect herbivores [plant sucking (PS), pod feeders (PF) and foliar feeders (FF)] and spiders (SPID).

Biomass

Prior to cover crop termination, barley biomass was estimated within each plot by clipping all barley vegetation within a 0.25 m2 quadrat randomly placed in three and four areas within each plot during years 2013 and 2014, respectively. Early kill plot biomass samples were harvested immediately before herbicide application in mid-April. In fallow, late kill and flail mow plots, biomass samples were taken immediately before burn down herbicide application in late May. Samples were placed in brown paper bags taken back to the laboratory and weighed after drying for roughly two weeks at 21°C.

Statistical Analyses

Foliar arthropod counts were subjected to a repeated-measure analysis of variance (ANOVA) (SAS Academic Edition, SAS Institute 2015) with treatment as a fixed factor, replicate designated as a random factor and date as the repeated measure. The PROC MIXED model was constructed to conduct an orthogonal contrast between treatment comparisons. Preplanned comparison consisted of Early Kill (EK) vs. Late Kill (LK), Flail Mow (FM) vs. LK and Fallow (F) vs. pooled Cover Crop (CC) treatments. These contrasts were made to compare effects of early to late season and mechanical to chemical termination practices, and compare the impact of cover cropping to fallow on the arthropod community within soybean.

Results

Biomass

Biomass samples from 2013 averaged 1678.22 kg/ha in fallow (F), 3593.73 kg/ha in FM, 72.33 kg/Ha in EK and 3741.25 kg/Ha in LK (Table 1). For 2014, 179.29 kg/ha of biomass was collected in F, 763.04 kg/Ha in FM, 211.25 kg/ha in EK and 651.7267 kg/ha in LK. Late terminated cover crop treatments showed at least a ~1900 kg per hectare increase in biomass over EK treatments in both years at both locations.

Arthropod Foliar Counts

In total, 68 families of arthropods (insects and spiders) were collected via sweep samples. The distribution and grouping into feeding guilds of these families are shown in Table 2.

Early vs. late season termination of cover crops

2013 Growing Season. Plant sucking insects were more numerous in EK compared to LK throughout the growing season at the Beltsville location ($F_{3,93}$ = 7.43, P = 0.0002, Figure 1). There were significantly higher numbers of spiders in LK compared to EK ($F_{3,93}$ = 3.31, P = 0.02, Figure 2). Excluding one date, spiders were more abundant in LK compared to EK plots for the 2013 growing season at the Beltsville location. The Upper Marlboro location contained significantly greater number of sucking predators in LK compared to EK treatment in 2013 ($F_{3,93}$ = 3.64, P = 0.016, Figure 3). The stink bug (Pentatomidae) parasitoid, *Telenomus podisi* was found in significantly greater numbers in FM compared to LK and EK compared to LK treatment ($F_{3,93}$ = 5.07, P = 0.027; $F_{3,93}$ = 8.89, P = 0.008, Figure 10).

2014 Growing Season: For the 2014 growing season pod feeding insects were significantly higher in EK compared to LK treatments at the Upper Marlboro location ($F_{3,165}$ = 5.18, P = 0.002, Figure 4). Chewing predators were more numerous in EK compared to LK treatments at the Upper Marlboro location in 2014 ($F_{3,165}$ = 2.12, P = 0.00993, Figure 5).

Plant sucking insects were more abundant in EK compared to LK treatments at the Beltsville location ($F_{3,177} = 16.67$, $P < 0.0001$, Figure 6). Pod feeding insects were present at higher abundances in the LK treatments compared to EK throughout the growing season at the Beltsville location ($F_{3,177} = 4.88$, $P = 0.003$, Figure 7). Spiders were found at significantly higher abundances in LK compared to EK throughout the growing season at the Beltsville location ($F_{3,177} = 6.64$, $P = 0.0003$, Figure 8). Chewing predators were found at significantly higher abundances throughout the growing season at the Beltsville, with populations increasing in late July and early August ($F_{3,177} = 4.77$, $P = 0.003$, Figure 10).

Chemical vs. mechanical termination

2013 Growing Season: Spiders, plant sucking and other insect guilds did not differ significantly between FM and LK treatments at the Beltsville or Upper Marlboro location ($P>0.05$).

2014 Growing Season: Spiders were found at a significantly greater number in LK compared to FM treatments ($F_{3,177}= 7.67$ $P=0.003$) at the Beltsville location. There was no significant difference between the LK and FM treatments at the Beltsville location for plant sucking insects ($P>0.05$). There was no significant difference between plant sucking insects or spiders in LK compared to FM treatments at the Upper Marlboro location ($P>0.05$).

Discussion

Cover crop termination practices have been shown to impact pest management via resulting residues that remain in the cropping system (Tremelling et al. 2002). Thus, it was hypothesized that different cover crop termination methods examined during this study would influence the arthropod community differently. As expected, cover crop biomass in LK was significantly greater than in EK plots. Cover crop biomass was on average 1 kg greater in FM and LK than in EK treatment across all years. Thus, it was hypothesized that this would result in an increase in predators such as spiders that are known to be linked with cover crop density (Young and Edwards 1990, Sunderland 1999, Sunderland and Samu 2000, Chen et al. 2011). Additionally, fallow (F) plots which had some weeds prior to herbicide spray had limited amounts of weed residue shortly after spraying. Thus, it was not anticipated that residue in fallow plots would have a significant impact on predator numbers during the sampling period.

Chemical (LK) and mechanical (FM) termination tactics impact on the arthropod community was similar among treatments. This suggests that whether cover crops are terminated chemically or by mowing, the response of the arthropod community will be similar. Comparisons of cover crop termination between chemical and mechanical methods have evaluated use of a roller crimper (Mirsky et al. 2012). Roller crimper is expected to leave more cover crop residue on the soil surface for a longer period of time than mowing. As opposed to cutting the cover crop in small pieces, the roller crimper rolls it over keeping the plant and root system in tack. Thus, using this method of cover crop termination may have resulted in difference among the arthropod community between mechanical and chemically terminated cover crop.

Late kill and EK tactics are the most widely used practices for cover crop termination by Maryland soybean producers. The majority of producers choose to terminate their cover crop early (early April) as opposed to late (at soybean planting ~ May 15). However, during this study, LK plots had the greatest abundance of chewing predators in 2014 and spiders in 2013 and 2014 at the Beltsville site. Plant sucking insects were demonstrably lower in abundance in LK plots. This may have occurred because weed abundance was greater in EK plots which attracted greater number of plant sucking insects such as plant and leaf hoppers. Additionally, increased abundances of predators in LK plots may have contributed to reductions in herbivore numbers. The increased abundance of predators were only noted in chewing predators and spiders for each study year at both locations. However, these predators comprised 73% of the total number of predators sampled. Results of this study are similar to others which found increased numbers of spiders throughout the growing season in habitats with high cover crop residue (Riechert 1999, Davis et al. 2010, Nascente et al. 2013, Blubaugh et al. 2016). However, our findings were in variance to Bryant et al. (2014) who found no impact of high cover crop biomass on herbivore numbers.

Conclusion

Overall, these results indicate that Maryland producers' cover crop termination methods that results in greater cover crop biomass may enhance some natural enemies and reduce the number of some pest species. More specifically spiders and some chewing predators may be augmented in those field where there is a delay in cover crop termination and fewer plant hoppers may colonize these habitats. However, the exact mechanism of greater number of spiders and chewing predators is unknown. It is unclear whether these predators were influenced by the shelter and/or alternative prey provided by the residue. It is possible that because the cover crop was allowed to grow for a lengthier period of time in LK compared to EK plots, there was more time for these predators to colonize LK habitats in direct response to the live vegetation prior to soybean planting. Knowing this information can lead to directed approaches for predator manipulation.

Appendices

Table I: Biomass data from the 2013 and 2014 growing seasons collected early season

Barley Biomass kg/ha

Location	Year	Treatment	Biomass kg/ha	Error
Beltsville	2013	EK	23.23	12.56
		LK	5599.02	184.43
		FM	5121.37	246.82
		F	3096.87	749.14
Beltsville	2014	EK	310.825	24.29
		LK	1083.08	286.89
		FM	1090.82	296.71
		F	271.60	83.88
Upper Marlboro	2013	EK	121.43	29.41
		LK	1883.48	215.27
		FM	2066.09	128.67
		F	259.57	83.44
Upper Marlboro	2014	EK	111.675	14.21
		LK	436.05	123.13
		FM	435.25	119.40
		F	86.98	27.55

Table II arthropod mean counts Upper Marlboro 2013

Treatment	Guild				Upper Marlboro 2013 Mean ± SE				
		July 10th	July 17th	July 24th	Aug 2nd	Aug 8th	Aug 15th	Aug 22nd	Aug 30th
Fallow	**spid**	0.25±0.25	0.75±0.25	0.75±0.25	0.50±0.29	0.50±0.50	1.75±0.75	1.00±0.58	1.00±0.71
	CP	0.25±0.25	0.75±0.25	1.00±0.41	1.00±0.41	0.75±0.48	2.75±1.38	1.25±0.75	1.00±0.71
	FF	1.75±0.85	1.75±0.85	8.50±2.1	1.75±0.48	2.25±1.31	5.25±1.49	3.75±0.75	3.00±0.71
	PF	0	0	0	0.25±0.25	0	0.25±0.25	1.50±0.65	0.25±0.25
	PS	3.00±1.08	5.00±1.73	7.25±1.49	2.25±0.75	2.75±1.70	25.75±2.93	14.00±4.38	2.50±1.04
	SP	1.00±0.41	1.50±0.96	0.75±0.48	1.25±0.95	1.25±0.95	14.5±1.19	7.50±0.65	3.25±0.75
Early Kill	**spid**	0	0.50±0.50	1.25±0.48	0.75±0.25	1.00±0.58	0.75±0.48	1.00±0.41	1.75±0.25
	CP	0	1.00±0.71	2.00±0.91	1.25±0.63	1.25±0.75	2.50±0.96	1.50±0.65	1.75±0.25
	FF	1.25±0.63	2.75±0.85	8±3.29	2.00±1.68	4.50±2.72	2.75±1.11	6.00±3.39	4.75±1.49
	PF	0.50±0.29	0	0	0	0	0	5.50±2.96	0.25±0.25
	PS	3.25±0.63	5.25±1.49	8.50±1.04	4.25±3.25	4.25±2.46	22.75±5.76	15.50±1.44	3.75±0.95
	SP	1.25±0.63	1.50±0.50	2.00±0.58	1.50±0.87	2.00±1.22	11.75±4.17	9.50±2.66	6.50±2.22
Flail Mow	**spid**	0.25±0.25	0.25±0.25	0.75±0.48	0.50±0.29	0.25±0.25	0.25±0.25	2.25±0.75	1.50±0.96
	CP	0.50±0.29	0.50±0.29	0.75±0.48	0.75±0.25	0.25±0.25	2.00±0.58	3.50±0.87	1.50±0.96
	FF	1.00±1	2.25±0.75	7.75±2.43	0.75±0.25	2.00±1.22	0.75±0.25	2.75±0.85	6.25±1.25
	PF	0.25±0.25	0	0	0	0	1.00±0.71	2.75±0.85	0
	PS	5.50±0.96	8.50±2.6	5.25±2.506	3.50±0.87	1.50±0.96	50.75±18.28	20±6.96	4.5±0.87
	SP	1.25±0.25	2.50±1.19	1.50±0.29	1.50±0.87	1.00±0.71	12.25±2.29	7.00±1.78	5.00±1.00
Late Kill	**spid**	0.75±0.48	0.25±0.25	2.00±0.58	0.25±0.25	0	1.25±0.25	0.50±0.29	0.75±0.48
	CP	1.25±0.95	0.25±0.25	2.50±0.65	0.25±0.25	0.50±0.29	4.25±2.509	1.00±0.00	0.75±0.48
	FF	0.50±0.50	2.00±1.41	6.25±2.78	1.00±0.41	2.75±2.14	3.25±0.48	2.75±0.85	1.00±0.41
	PF	0	0.25±0.25	0	0.25±0.25	0	0.25±0.25	4.00±1.87	0
	PS	3.75±0.85	4.25±0.75	6.25±0.85	2.25±0.85	1.50±1.19	22.50±4.84	16.25±5.19	2.00±0.82
	SP	1.00±0	1.50±0.87	1.00±0.41	2.00±1.22	1.25±0.75	10±3.49	5.25±1.6	0.50±0.50

Table III Arthropod Mean counts Beltsville 2013

Treatment	Guild	July 10th	July 17th	July 24th	July 31st	Aug 7th	Aug 14th	Aug 21st	Aug 28th
					Beltsville 2013 Mean±SE				
Fallow	**spid**	1.00±0.41	0.75±0.48	1.00±0.41	1.00±0.41	3.25±1.25	1.25±0.48	1.75±0.48	1.25±0.95
	CP	0	0	0.25±0.25	0	0	0	0	0.75±0.48
	FF	8.50±2.503	10.50±1.32	9.25±4.13	7±2.61	8±3.34	2.50±1.19	2.00±0.91	2.50±0.96
	PF	0.25±0.25	0	2.00±1.35	0.25±0.25	3.00±0.71	1.75±0.25	0	1.50±1.19
	PS	4.00±1.58	8.25±2.78	3.00±1.47	2.75±0.85	1.50±0.29	2.25±0.95	4.25±0.63	2.50±1.505
	SP	2.00±1.22	3.75±1.25	4.00±0.91	3.50±0.65	10.00±2.68	2.50±0.50	11.00±0.71	5±2.68
Early Kill	**spid**	0.25±0.25	0.75±0.48	1.00±0.41	1.50±0.65	0.75±0.25	1.25±0.48	2.75±0.85	0.25±0.25
	CP	0	0.25±0.25	0.25±0.25	0.50±0.29	0.25±0.25	0.25±0.25	0	1.00±0.41
	FF	9.00±2.65	8.75±3.9	7±5	4.00±2.12	4.75±2.02	1.25±0.63	3.25±0.75	2.25±1.31
	PF	0	0	0.50±0.29	1.00±1	4.25±2.02	1.25±0.95	0	1.00±0.41
	PS	8.75±2.50	5.25±1.6	8±2.68	2.00±1.15	3.75±0.85	1.75±0.48	5.50±1.32	3.25±0.85
	SP	1.25±0.75	1.25±0.48	1.75±0.48	3.50±0.50	15.25±0.75	2.25±0.75	12.50±1.85	4.25±1.44
Flail Mow	**spid**	0.25±0.25	1.75±0.85	1.00±0.58	1.50±0.65	2.00±0.71	1.50±0.65	1.50±0.50	0.75±0.25
	CP	0	0	0	0.25±0.25	0.25±0.25	0.75±0.75	0	0.75±0.75
	SP	1.50±0.50	7.50±2.87	2.50±0.65	3.75±1.03	14.00±2.16	4.75±1.25	11.00±1.47	5.25±2.50
	PF	0	0.25±0.25	2.00±0.41	0	2.00±0.71	1.00±0.41	0.25±0.25	2.25±1.6
	PS	4.75±1.93	3.50±1.44	4.00±1.29	2.00±1.41	0.50±0.29	1.00±0.41	4.75±1.49	3.75±0.95
	FF	10.00±2.48	6.00±0.71	5.25±2.29	6.75±2.14	5.50±2.4	1.25±0.48	1.75±0.63	10±4.95
Late Kill	**spid**	1.75±0.85	2.25±0.85	1.50±0.65	2.75±0.63	4.00±0.71	0.75±0.48	4.25±0.63	2.00±0.71
	CP	0	0	0.25±0.25	0	0	0	0.75±0.25	0.25±0.25
	FF	10.50±2.63	8.00±0.41	4.75±1.8	5±4.67	2.50±0.65	1.00±0.41	8.00±6.06	2.50±0.87
	PF	0.25±0.25	0.50±0.29	1.25±0.48	2.25±1.65	2.75±0.75	2.25±0.75	0	2.50±1.85
	PS	3.75±1.44	4.25±0.48	3.75±0.75	1.00±0.00	1.50±0.65	0.75±0.25	5.50±0.65	3.00±0.41
	SP	0.25±0.25	3.00±1.08	6.50±2.90	2.75±0.85	12.00±2.12	2.75±1.25	8.50±1.26	5.00±1.22

Table IV Arthropod Mean counts by date in Upper Marlboro 2014

					Upper Marlboro 2014 Mean±SE						
Treatment											
BG	**July 2nd**	**July 10th**	**July 15th**	**July 23rd**	**July 30th**	**Aug 6th**	**Aug 13th**	**Aug 20th**	**Aug 27th**	**Sept 9th**	**Sept 10th**
CP	0.50±0.50	0	0	1.00±1	0.50±0.50	0.75±0.25	1.25±0.95	0.75±0.48	1.25±0.75	3.00±1.47	0.50±0.29
FF	0.50±0.50	0.50±0.50	1.25±0.95	3.00±1.29	1.25±0.75	0.75±0.75	0	0	0	0	0
PF	2.25±0.63	1.75±0.48	2.50±0.96	1.00±0.58	2.00±0.58	2.25±1.31	1.00±0.41	1.50±1.19	1.25±0.95	4.5±2.96	5±1.68
PS	3.25±1.31	7.75±2.93	22.75±4.59	4.00±0.71	2.50±0.65	1.00±0.58	2.00±0.41	1.25±0.95	1.25±0.95	0.25±0.25	0.50±0.29
SP	2.00±0.91	1.50±0.96	5.50±1.89	1.75±0.48	2.50±0.96	1.50±0.65	2.00±1.22	4.5±1.19	5.25±0.63	2.25±1.11	6.50±2.02
SPID	0.75±0.48	0.25±0.25	1.00±0.41	0.50±0.29	1.25±0.63	2.25±1.44	1.25±0.63	2.00±0.82	2.00±0.58	1.50±0.65	0.75±0.48
EK	**July 2nd**	**July 10th**	**July 15th**	**July 23rd**	**July 30th**	**Aug 6th**	**Aug 13th**	**Aug 20th**	**Aug 27th**	**Sept 9th**	**Sept 10th**
CP	0.75±0.48	0	0.25±0.25	0	0.25±0.25	1.00±0.71	0.75±0.48	1.50±0.65	0.50±0.29	0	0.25±0.25
FF	0.25±0.25	0.25±0.25	2.00±1.08	1.50±0.87	2.00±0.71	1.25±0.75	0.25±0.25	0	0.25±0.25	0	0
PF	2.00±0.71	2.00±1.35	3.00±0.71	0.75±0.75	3.00±1.47	1.00±0.71	2.00±0.91	3.00±2	1.25±0.48	3.75±1.75	1.25±0.63
PS	7.75±4.4	7±4.06	18.25±6.39	3.00±0.58	4.25±1.11	1.25±0.75	1.25±0.48	0	0.25±0.25	1.00±0.58	0.50±0.29
SP	5±1.58	0.75±0.75	7.75±1.65	1.00±0.58	2.75±1.11	1.50±0.87	3.00±1.08	1.75±0.48	2.75±0.85	5.75±2.06	6.25±1.97
SPID	3.00±1.22	0.25±0.25	1.75±0.48	0.25±0.25	1.00±0.71	1.00±0.58	1.50±0.87	1.25±0.48	0.25±0.25	1.50±0.65	1.00±0.58
FM	**July 2nd**	**July 10th**	**July 15th**	**July 23rd**	**July 30th**	**Aug 6th**	**Aug 13th**	**Aug 20th**	**Aug 27th**	**Sept 9th**	**Sept 10th**
CP	0	0	0	0.50±0.50	0.25±0.25	0.50±0.29	0.50±0.29	0.75±0.48	0.75±0.75	0	0.75±0.48
FF	0	0.50±0.50	0.75±0.48	0.75±0.75	0.50±0.29	0.50±0.50	0	0	0	0.25±0.25	0
PF	0.25±0.25	2.75±2.1	2.25±0.75	0.25±0.25	0.75±0.48	1.00±0.71	0.75±0.48	3.25±1.65	1.50±1.50	0.50±0.29	0
PS	3.50±1.19	6.50±2.72	22.50±3.8	6.75±3.35	3.00±0.71	1.25±0.48	0.50±0.50	0.50±0.29	0.75±0.48	0.75±0.75	0.50±0.29
SP	3.25±0.63	1.25±0.48	6.00±1.47	1.25±1.25	1.75±0.85	2.00±0.91	2.25±1.03	3.50±0.87	3.75±1.75	4.25±1.31	9±1.08
SPID	1.00±0	0.50±0.50	0.25±0.25	1.75±1.03	1.00±0.71	0.50±0.29	0.75±0.25	2.00±1.22	1.50±0.65	1.50±0.29	0.75±0.25
LK	**July 2nd**	**July 10th**	**July 15th**	**July 23rd**	**July 30th**	**Aug 6th**	**Aug 13th**	**Aug 20th**	**Aug 27th**	**Sept 9th**	**Sept 10th**
CP	0.25±0.25	0	0	0.25±0.25	1.00±0.41	2.00±0.71	2.00±0.71	1.75±0.75	0	0	0.50±0.50
FF	0.50±0.29	0.75±0.48	1.00±0.41	1.50±0.29	1.25±0.25	0.25±0.25	1.00±1.00	0.25±0.25	0	0	0
PF	0	2.25±2.25	2.50±0.65	1.00±0.58	2.25±0.95	1.00±0.58	0.25±0.25	1.00±0.71	0.75±0.75	3.50±1.71	2.00±1.41
PS	1.50±0.96	1.50±0.65	13.50±1.94	6.25±2.503	3.00±0.71	2.00±0.41	1.50±0.29	0.75±0.25	0.75±0.48	1.25±0.48	0
SP	1.50±0.87	1.25±0.25	3.50±1.76	1.00±0.58	4.00±0.58	2.00±1.22	2.50±0.29	3.75±1.49	2.50±1.04	5.50±1.19	6.25±2.32
SPID	3.50±1.71	0.75±0.48	1.00±0.41	0.50±0.50	1.75±0.25	1.00±0.71	1.00±0	1.00±0	1.00±0.71	0.75±0.25	0.50±0.29

Table V Arthropod Mean counts by date in Beltsville 2014

Table V Arthropod Mean counts by date in Beltsville 2014

Treatment					Mean±SE							
BG	**July 1st**	**July 8th**	**July 15th**	**July 22nd**	**July 29th**	**Aug 5th**	**Aug 13th**	**Aug 19th**	**Aug 26th**	**Sept 2nd**	**Sept 9th**	**Sept 16th**
PF	1.00±0.41	2.25±1.03	0.75±0.48	0	1.25±0.48	1.00±0.71	1.00±0.41	0.75±0.48	1.75±0.75	0.25±0.25	4.00±2.35	2.75±1.505
CP	0	0.25±0.25	0.50±0.50	0.25±0.25	0.50±0.29	0.50±0.50	0.75±0.25	1.00±0.71	1.25±0.63	0.25±0.25	0.50±0.50	1.25±0.63
FF	1.00±0.41	1.50±0.96	2.50±1.32	2.75±0.25	10.25±2.95	2.50±1.19	3.00±0.91	1.50±0.50	1.50±0.65	0.25±0.25	1.75±0.75	1.75±0.85
PS	4.25±1.55	9.00±2.04	4.75±1.25	6.25±0.85	3.75±1.11	2.25±0.48	0.75±0.48	1.50±0.50	1.75±0.63	1.75±0.75	2.50±1.04	1.75±0.75
SP	5.25±1.49	2.25±1.31	2.50±0.87	2.75±0.85	3.25±0.95	0.75±0.75	4.00±1.63	5.75±2.14	8.00±1.83	7.50±2.503	5.00±1.08	7.50±1.26
SPID	1.00±0.58	1.00±0.00	0.25±0.25	0.50±0.50	1.50±1.19	1.50±0.65	1.75±0.48	1.00±0.41	1.75±0.75	0.75±0.48	1.00±0.41	3.00±0.71
EK	**July 1st**	**July 8th**	**July 15th**	**July 22nd**	**July 29th**	**Aug 5th**	**Aug 13th**	**Aug 19th**	**Aug 26th**	**Sept 2nd**	**Sept 9th**	**Sept 16th**
PF	3.50±0.87	2.25±1.31	1.00±0.41	1.50±0.87	1.50±0.50	0.25±0.25	1.25±0.63	2.25±1.03	0.75±0.25	1.75±1.11	1.50±0.96	1.75±0.48
CP	1.50±0.65	0	0.25±0.25	0.50±0.50	2.00±0.41	0	0.75±0.48	2.50±0.65	1.00±0.41	0.50±0.50	1.50±0.87	3.75±0.75
FF	3.75±1.18	1.25±0.48	2.00±1.08	1.75±0.75	4.5±0.50	2.25±1.93	2.00±0.71	2.50±0.96	1.00±1.00	1.50±1.19	1.00±0.41	1.00±0.71
PS	18.75±5.72	9.50±3.66	5.25±1.65	8.25±1.44	3.50±1.04	1.00±0.41	0.50±0.29	1.75±0.48	1.50±0.29	2.00±0.41	2.25±0.48	1.25±0.63
SP	9.75±2.46	4.75±1.505	2.50±0.65	1.00±0.41	2.00±0.71	0.50±0.29	3.75±1.11	6.00±1.78	3.75±1.38	9.50±2.06	6.25±2.39	5.25±1.70
SPID	4.00±0.71	0.50±0.29	0.25±0.25	1.75±0.63	1.00±0.41	0	1.00±0.41	1.75±0.63	1.50±0.65	1.25±0.48	1.50±0.65	1.25±0.75
FM	**July 1st**	**July 8th**	**July 15th**	**July 22nd**	**July 29th**	**Aug 5th**	**Aug 13th**	**Aug 19th**	**Aug 26th**	**Sept 2nd**	**Sept 9th**	**Sept 16th**
PF	0.50±0.29	0.75±0.25	0.50±0.29	0.25±0.25	1.00±0.41	0.75±0.48	0.25±0.25	0.75±0.48	0.25±0.25	0.50±0.29	4.00±1.08	3.50±1.89
CP	0	0	0	0	2.00±0.58	0.50±0.29	0.25±0.25	1.00±0.71	1.00±0.41	0.50±0.29	1.00±0.58	1.25±0.48
FF	1.50±0.65	2.00±0.58	2.50±1.66	7.50±4.21	5.50±2.25	1.75±1.44	3.75±2.509	2.50±0.87	1.75±0.63	1.25±0.48	0.75±0.25	0.25±0.25
PS	5.25±0.75	5.00±1.22	3.50±1.04	9.00±1.91	4.00±1.58	1.25±0.25	0	2.00±1.41	0.50±0.29	0.50±0.29	3.50±1.19	1.75±0.25
SP	4.00±1.58	3.75±0.75	2.00±0.71	2.75±1.03	1.25±0.48	1.00±0.71	5.00±1.68	7.25±1.11	6.00±2.27	8.00±2.74	4.75±1.11	7.50±1.04
SPID	0.75±0.25	0.25±0.25	0	0.25±0.25	0.75±0.48	0.25±0.25	0.25±0.25	0.75±0.25	2.00±0.58	1.75±0.75	0.50±0.29	1.50±0.29
LK	**July 1st**	**July 8th**	**July 15th**	**July 22nd**	**July 29th**	**Aug 5th**	**Aug 13th**	**Aug 19th**	**Aug 26th**	**Sept 2nd**	**Sept 9th**	**Sept 16th**
PF	1.00±0.71	0.75±0.48	0.50±0.29	0.25±0.25	1.00±0.58	0.50±0.50	0.25±0.25	1.00±0.58	0	1.00±0.41	3.50±1.85	2.75±0.75
CP	0.50±0.50	0	0	0.50±0.50	2.00±1.08	1.25±0.75	0.25±0.25	0.50±0.29	1.25±0.48	0.75±0.48	0.75±0.48	4.00±1.73
FF	2.00±0.41	1.25±0.63	3.00±1.22	5.50±3.66	4.25±1.38	1.50±0.65	2.00±2.00	2.25±0.63	1.50±0.96	0	0.50±0.50	0
PS	5.00±1.15	4.50±1.19	6.50±2.10	5.75±2.10	0.75±0.25	0.75±0.48	0.50±0.50	1.50±0.65	0.75±0.48	1.00±0.58	0.75±0.25	1.50±0.65
SP	6.00±1.58	3.00±1.35	3.00±1.08	1.50±0.87	1.25±0.48	0.25±0.25	6.25±2.72	6.50±1.85	3.00±0.91	6.75±1.11	2.25±1.31	7.50±3.28
SPID	0.75±0.48	0.75±0.48	0.50±0.29	0.75±0.48	1.25±0.48	0	1.75±0.85	1.25±0.25	1.75±0.85	2.00±0.41	1.75±0.85	2.00±0.91

Table VI: Insect families collected by feeding guild

Chewing Predators (CP)	Foliar Feeders (FF)	Plant Sucking (PS)
Salticidae Lycosidae Aranae Oxyopidae Thomisidae Clubionidae Ctenidae Tetragnathidae Lyniphidae Pholcidae Carabidae Cicindelinae Lampyridae Syrphidae (Larvae) Mantidae Chrysopidae Coccinellidae	Cydnidae Chrysomelidae Erebidae Meloidae Arctiidae Hesperiidae Noctuidae Coccinellidae Elateridae Cassidinae Scarabaeidae Harpalinae	Scarabaeidae Cicadellidae Membracidae Aphididae Alydidae Miridae
Sucking Predators (SP)	**Spiders**	**Parasitoid Wasps**
Hemerobiidae Pentatomidae Reduviidae Geocoridae Anthocoridae Nabidae Asilidae Pentatomidae Cydnidae Chrysomelidae	Salticidae Lycosidae Aranae Oxyopidae Thomisidae Clubionidae Ctenidae Tetragnathidae Lyniphidae Pholcidae	Chalcididae Proctotrupoidae Braconidae Eulophid Cynipidae Ichnumonidae Chrysididae Tiphiidae Aphelinidae Pompilidae Ooencyrtus Polistinae Scoliidae

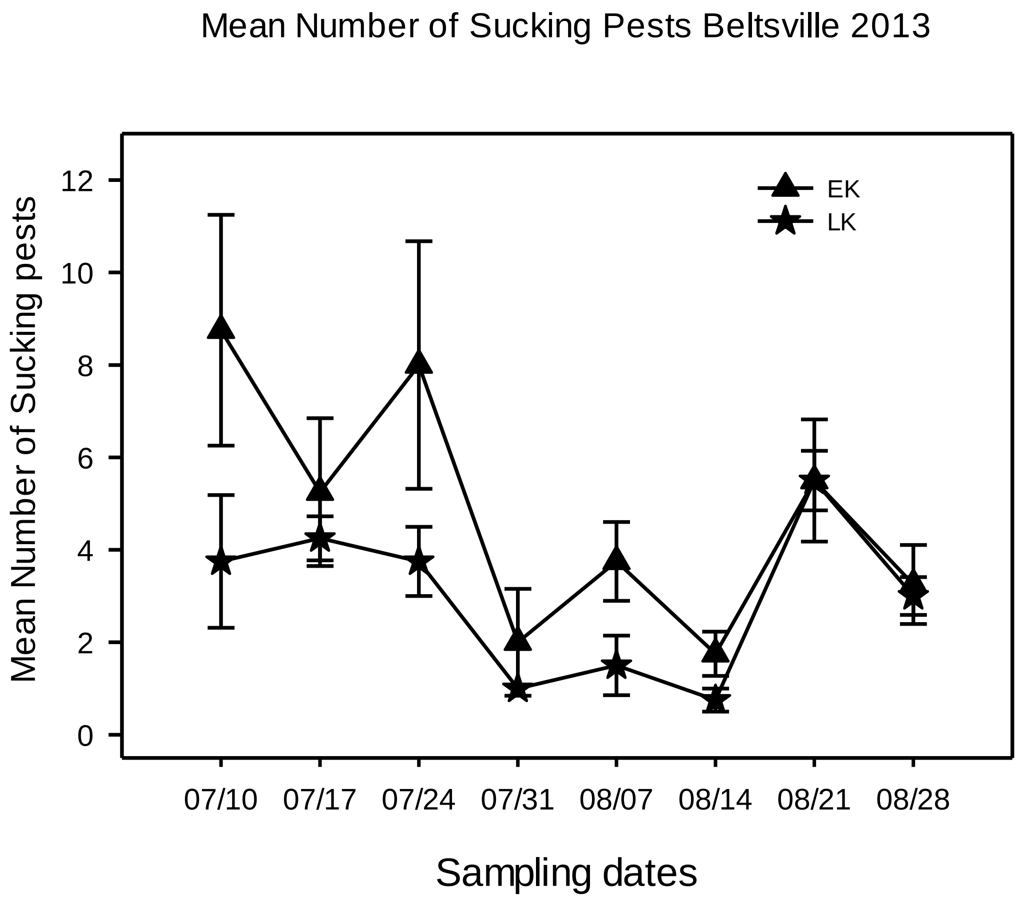

Figure I: Mean number of sucking pests/stem feeding insect counts per treatment by date for the 2013 growing season in Beltsville, Maryland. Early Kill = EK (Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

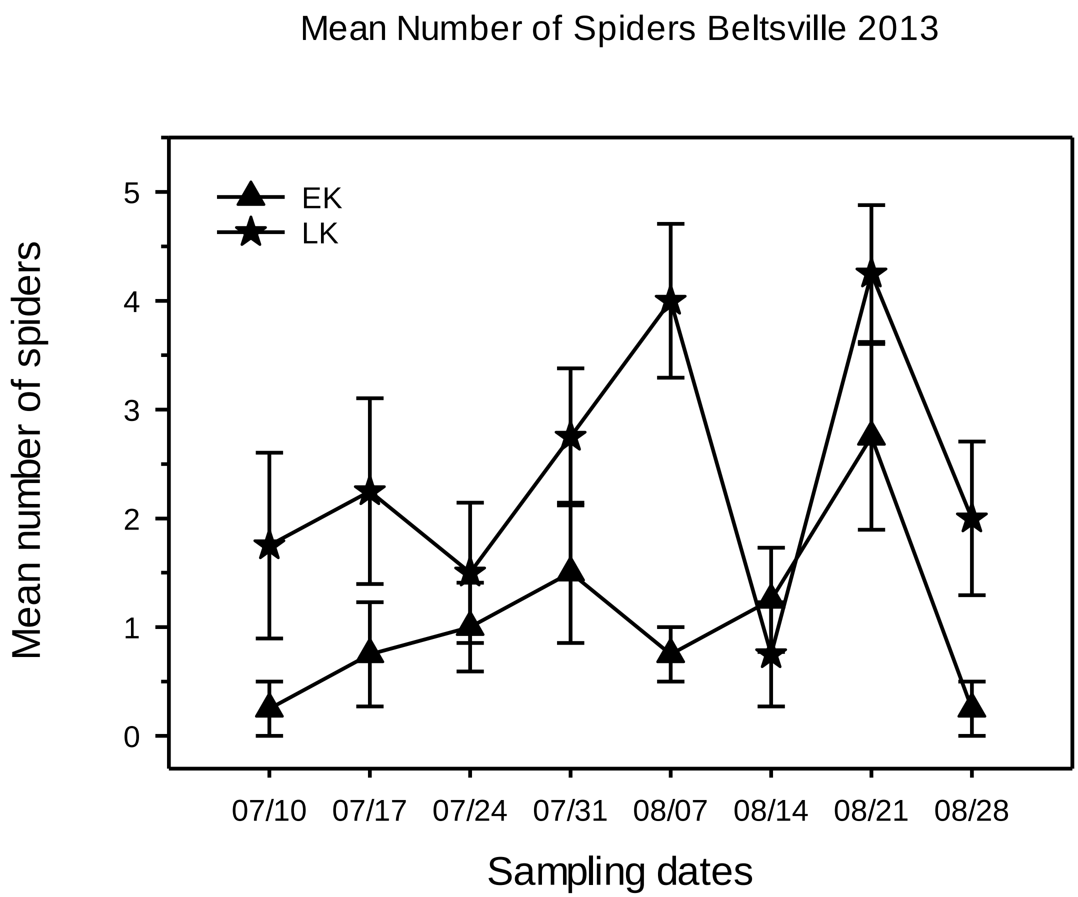

*Figure II:*Mean number of individual spider counts per treatment by date for the 2013 growing season in Beltsville, Maryland. Early Kill = EK(Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

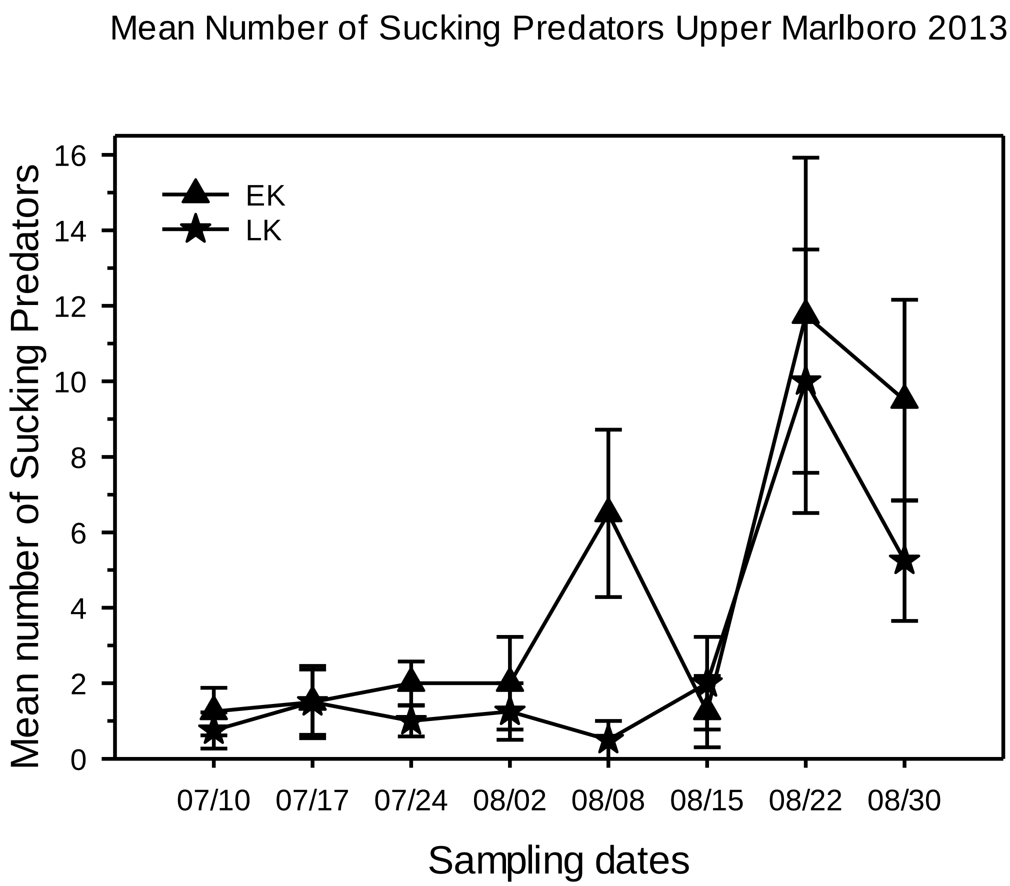

*Figure III:*Mean number of individual sucking/ hemipteran predator counts per treatment by date for the 2013 growing season in Upper Marlboro, Maryland. Early Kill = EK(Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

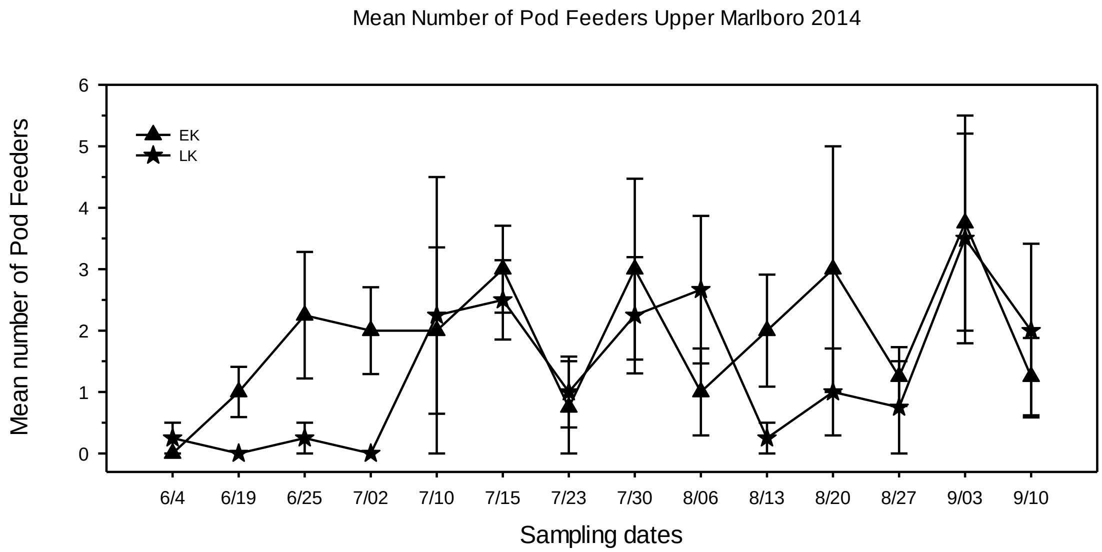

*Figure IV:*Mean number of individual plant sucking /stem feeding insect counts per treatment by date for the 2014 growing season in Upper Marlboro, Maryland. Early Kill = EK(Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

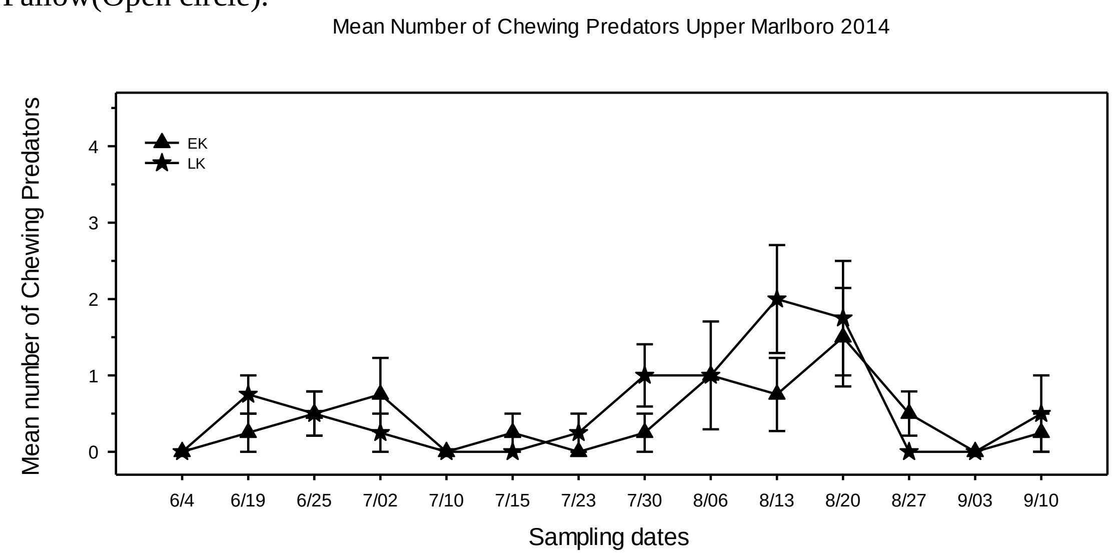

*Figure V:*Mean number of individual chewing predator counts per treatment by date for the 2014 growing season in Upper Marlboro, Maryland. Early Kill = EK(Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

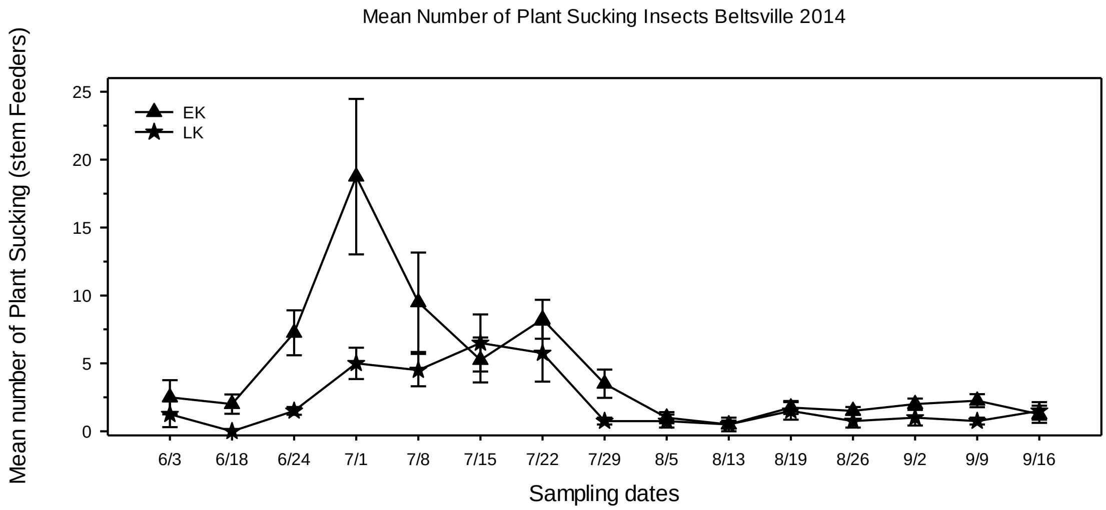

*Figure VI:*Mean number of individual plant sucking /stem feeding insect counts per treatment by date for the 2014 growing season in Beltsville, Maryland. Early Kill = EK(Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

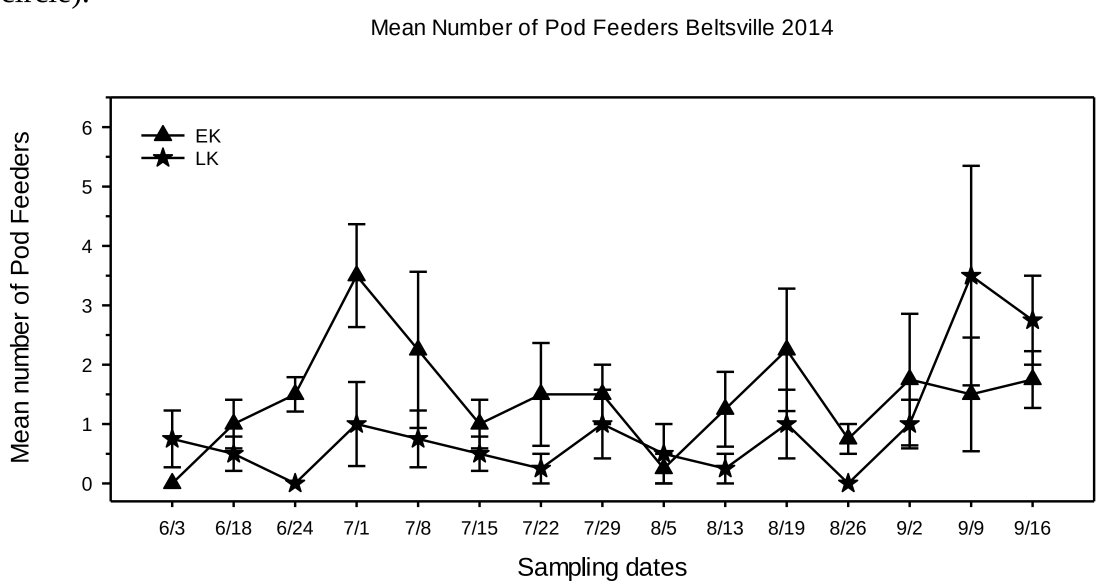

*Figure VII:*Mean number of individual Pod Feeding pest insect counts per treatment by date for the 2014 growing season in Beltsville, Maryland. Early Kill = EK(Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

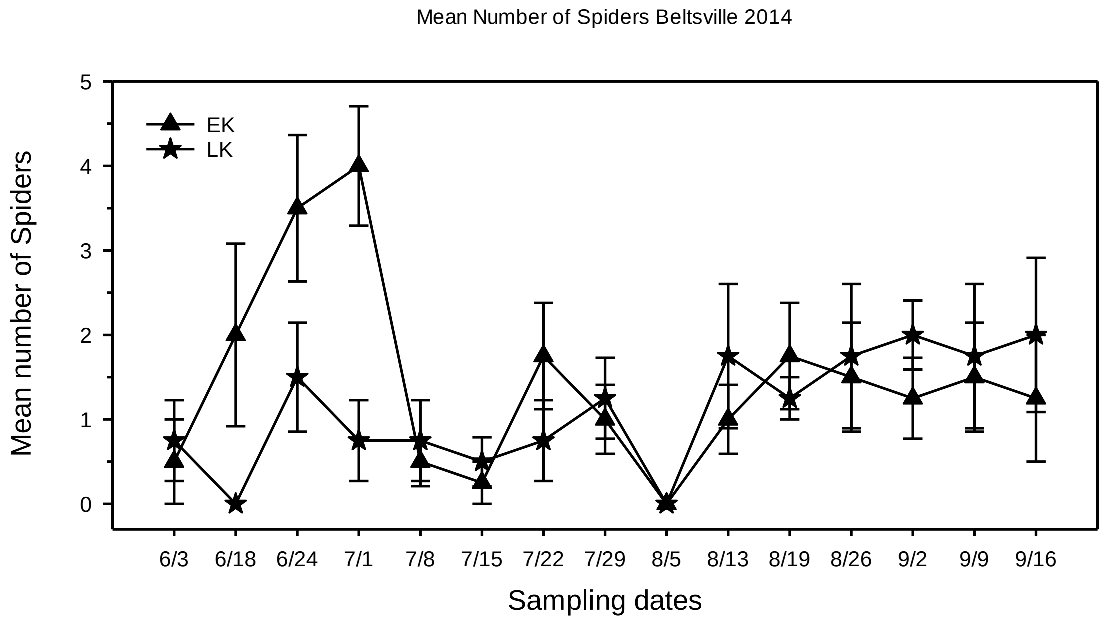

*Figure VIII:*Mean number of individual spiders counts per treatment by date for the 2014 growing season in Beltsville, Maryland. Early Kill = EK(Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

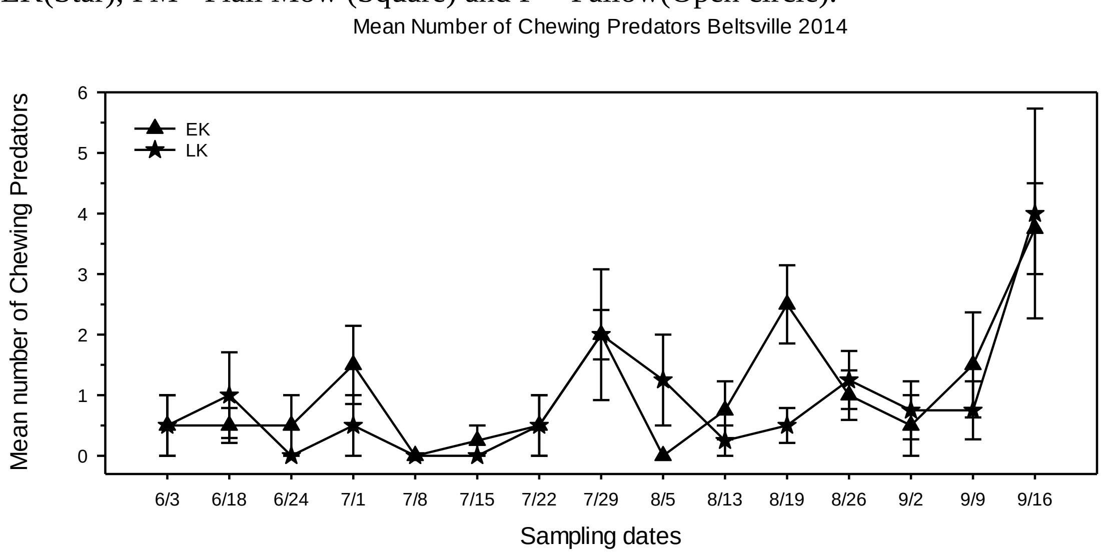

*Figure IX:*Mean number of individual chewing predator counts per treatment by date for the 2014 growing season in Beltsville, Maryland. Early Kill = EK(Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

Mean number of *Telenomus podisi* Upper Marlboro 2013

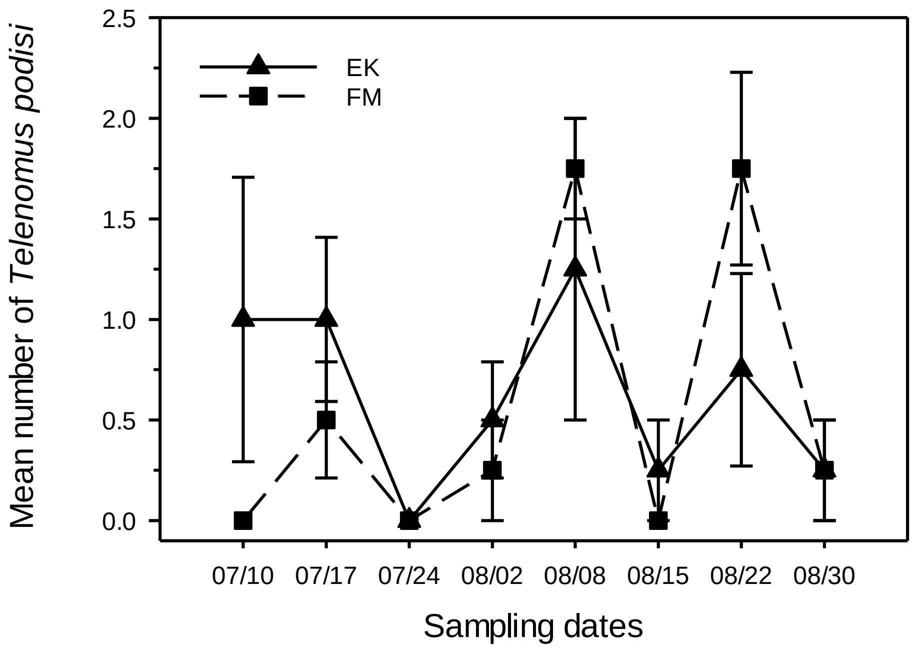

*Figure X:*Mean number of individual *Telenomus podisi* parasitoid wasps per treatment by date for the 2014 growing season in Beltsville, Maryland. Early Kill = EK(Triangle), Late Kill = LK(Star), FM= Flail Mow (Square) and F = Fallow(Open circle).

References

(Maryland Cover Crop Program). **2014**. Maryland Cover Crop Program. (http://www.qascd.com/maryland-cover-crop-program/).

Altieri, M. A. 1999. The ecological role of biodiversity in agroecosystems. Agric. Ecosyst. Environ. 74: 19–31.

Andow, D. A. 1990. Population dynamics of an insect herbivore in simple and diverse habitats. Ecology. 71: 1006–1017.

Aulakh, J. S., A. J. Price, S. F. Enloe, E. van Santen, G. Wehtje~~,~~ and M. G. Patterson. **2012**. Integrated Palmer amaranth management in glufosinate-resistant cotton: I. Soil-inversion, high-residue cover crops and herbicide regimes. Agronomy. 2: 295–311.

Bahlai, C. A., R. M. Weiss~~,~~ and R. H. Hallett. **2013**. A mechanistic model for a tritrophic interaction involving soybean aphid, its host plants, ~~A~~ and multiple natural enemies. Ecol. Modell. 254: 54–70.

Balfour, R. A.~~,~~ and A. L. Rypstra. **1998**. The influence of habitat structure on spider density in a no-till soybean agroecosystem. J. Arachnol. 26: 221–226.

Bianchi, F. J. J. A., C. J. H. Booij~~,~~ and T. Tscharntke. **2006**. Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proc. Biol. Sci. 273: 1715–1727.

Blubaugh, C. K., J. R. Hagler, S. A. Machtley~~,~~ and I. Kaplan. **2016**. Cover crops increase foraging activity of omnivorous predators in seed patches and facilitate weed biological control. Agric. Ecosyst. Environ. 231: 264–270.

Blubaugh, C. K.~~,~~ and I. Kaplan. **2015**. Tillage compromises weed seed predator activity across developmental stages. Biol. Control. 81: 76–82.

Bone, N. J., L. J. Thomson, P. M. Ridland, P. Cole, and A. A. Hoffmann. **2009**. Cover crops in Victorian apple orchards: Effects on production, natural enemies and pests across a season. Crop Prot. 28: 675–683.

Bottenberg, H., G. Frantz~~,~~ and H. C. Mellinger. **1999**. Refuge and cover crop plantings for beneficial insect habitats. Proc. Florida State Hortic. Soc. 339–341.

Brainard, D. C.~~,~~ and R. R. Bellinder. **2004**. Weed suppression in a broccoli–winter rye intercropping system. Weed Sci. 52: 281–290.

Bryant, A., D. C. Brainard, E. R. Haramoto~~,~~ and Z. Szendrei. **2013**. Cover crop mulch and weed management influence arthropod communities in strip-tilled cabbage. Environ. Entomol. 42: 293–306.

Bryant, A., T. Coudron, D. Brainard~~,~~ and Z. Szendrei. **2014**. Cover crop mulches influence biological control of the imported cabbageworm (*Pieris rapae* L., Lepidoptera: Pieridae) in cabbage. Biol. Control. 73: 75–83.

Buckelew, L. D., L. P. Pedigo, H. M. Mero, M. D. Owen~~,~~ and G. L. Tylka. **2000**. Effects of weed management systems on canopy insects in herbicide-resistant soybeans. J. Econ. Entomol. 93: 1437–1443.

Chen, L. L., M. S. You~~,~~ and S. B. Chen. **2011**. Effects of cover crops on spider communities in tea plantations. Biol. Control. 59: 326–335.

Davis, H. N., R. S. Currie, N. L. Klocke~~,~~ and L. L. Buschman. **2010**. Winter annual cover crop has only minor effects on major corn arthropod pests. J. Econ. Entomol. 103: 348–355.

Dunbar, M. W., A. J. Gassmann~~,~~ and M. E. O. Neal. **2012**. Effects of rye cover crop on arthropod communities.

Gill, H. K., R. McSorley~~,~~ and M. Branham. **2011**. effect of organic mulches on soil surface insects and other arthropods. florida entomol. 94: 226–232.

Jabbour, R., T. Pisani-Gareau, R. G. Smith, C. Mullen~~,~~ and M. E. Barbercheck. **2015**. Cover crop and tillage intensities alter ground-dwelling arthropod communities during the transition to organic production. Renew. Agric. Food Syst. 31: 361-374.

Jackson, D. M.~~,~~ and H. F. Harrison. **2008**. Effects of a killed-cover crop mulching system on sweet potato production, soil pests, and insect predators in South

Carolina. J. Econ. Entomol. 101: 1871–1880.

Kawashima, M.~~,~~ and C. Jung. **2010**. Effects of sheltered ground habitats on the overwintering potential of the predacious mite *Neoseiulus californicus* (Acari: Phytoseiidae in apple orchards on mainland Korea. Exp. Appl. Acarol. 55: 375–388.

Koch, R. L., P. M. Porter, M. M. Harbur, M. D. Abrahamson, K. A. G. Wyckhuys, D. W. Ragsdale, K. Buckman, Z. Sezen~~,~~ and G. E. Heimpel. **2012**. Response of soybean insects to an autumn-seeded rye cover crop. Environ. Entomol. 41: 750–760.

Landis, D. A., S. D. Wratten~~,~~ and G. M. Gurr. **2000**. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu. Rev. 45: 175–

Langellotto, G. A.~~,~~ and R. F. Denno. **2004**. Responses of invertebrate natural enemies to complex-structured habitats: A meta-analytical synthesis. Oecologia. 139: 1–10.

Lawton, J. H.~~,~~ and D. R. Strong Jr. 1981. Community patterns and competition in folivorous insects. Am. Nat. 118: 317–338.

Liebman, M.~~,~~ and E. Dyck. **1993**. Crop-rotation and intercropping strategies for weed management. Ecol. Appl. 3: 92–122.

Lundgren, J. G.~~,~~ and J. K. Fergen. **2011**. Enhancing predation of a subterranean insect pest: A conservation benefit of winter vegetation in agroecosystems. Appl. Soil Ecol. 51: 9–16.

Mirsky, S. B., M. R. Ryan, W. S. Curran, J. R. Teasdale, J. Maul, J. T. Spargo, J. Moyer, A. M. Grantham, D. Weber, T. R. Way, and G. G. Camargo. **2012**. Conservation tillage issues: Cover crop-based organic rotational no-till grain production in the mid-Atlantic region, USA. Renew. Agric. Food Syst. 27: 31–40.

Mirsky, S. B., M. R. Ryan, J. R. Teasdale, W. S. Curran, C. S. Reberg-Horton, J. T. Spargo, M. S. Wells, C. L. Keene, and J. W. Moyer. **2013**. Overcoming weed management challenges in cover crop–based organic rotational no-till soybean production in the eastern United States. Weed Technol. 27: 193–203.

Morton, T. A., J. S. Bergtold, and A. J. Price. **2006**. The Economics of Cover Crop Biomass for Corn and Cotton. pp. 69–76. *In R.C. Schwartz, et al., (eds.) proc. 28th Southern Conserv. Tillage Syst. Conf., Amarillo, TX. 26-28 June 2006. USDA-ARS Conserv. Prod. Res. Lab.*

Mulvaney, M. J., A. J. Price, and C. W. Wood. **2011**. Cover crop residue and organic mulches provide weed control during limited-input no-till collard production. J. Sustain. Agric. 35: 312–328.

Nascente, A. S., C. A. C. Crusciol, T. Cobucci, and E. D. Velini. **2013**. Cover crop termination timing on rice crop production in a no-till system. Crop Sci. 53: 2659–2669.

Navntoft, S., K. Kristensen, I. Johnsen, A. M. M. Jensen, L. Sigsgaard~~,~~ and P. Esbjerg. **2016**. Effects of weed harrowing frequency on beneficial arthropods, plants and crop yield. Agric. For. Entomol. 59–67.

Obermaier, E., A. Heisswolf, J. Poethke, B. Randlkofer~~,~~ and T. Meiners. **2008**. Plant architecture and vegetation structure: Two ways for insect herbivores to escape parasitism. Eur. J. Entomol. 105: 233–240.

Obrycki, J. J., J. D. Harwood, T. J. Kring~~,~~ and R. J. O'Neil. **2009**. Aphidophagy by Coccinellidae: Application of biological control in agroecosystems. Biol. Control. 51: 244–254.

Olson, D. M., R. F. Davis, S. L. Brown, P. Roberts~~,~~ and S. C. Phatak. **2006**. Cover crop, rye residue and in-furrow treatment effects on thrips. J. Appl. Entomol. 130: 302–308.

Peachey, R. E., A. Moldenke, R. D. William, R. Berry, E. Ingham~~,~~ and E. Groth. **2002**. Effect of cover crops and tillage system on symphylan (Symphlya: *Scutigerella immaculata*, Newport) and *Pergamasus quisquiliarum* Canestrini (Acari: Mesostigmata) populations, and other soil organisms in agricultural soils. Appl. Soil Ecol. 21: 59–70.

Price, A. J., F. J. Arriaga, R. L. Raper, K. S. Balkcom, T. S. Komecki~~,~~ and D. Wayne Reeves. **2009**. Comparison of mechanical and chemical winter cereal cover crop termination systems and cotton yield in conservation agriculture. J. Cotton Sci. 13: 238–245.

Reeves, R. B., J. K. Greene, F. P. F. Reay-Jones, M. D. Toews~~,~~ and P. D. Gerard. **2010**. Effects of adjacent habitat on populations of stink bugs (Heteroptera: Pentatomidae) in cotton as part of a variable agricultural landscape in South Carolina. Environ. Entomol. 39: 1420–1427.

Riechert, S. E. 1999. The hows and whys of successful pest suppression by spiders: Insights from case studies. J. Arachnol. 27: 387–396.

Smith, A. W., R. B. Hammond~~,~~ and B. R. Strinner. **1988**. Influence of rye-cover crop management on soybean foliage arthropods. Environ. Entomol. 17: 109–114.

Sunderland, K. 1999. Mechanisms underlying the effects of spiders on pest populations. J. Arachnol. 27: 308–316.

Sunderland, K.~~,~~ and F. Samu. **2000**. Effects of agricultural diversification on the abundance, distribution, and pest control potential of spiders. Entomol. Exp. Appl. 95: 1–13.

Tillman, G., H. Schomberg, S. Phatak, B. Mullinix, S. Lachnicht, P. Timper~~,~~ and

D. Olson. **2004**. Influence of cover crops on insect pests and predators in conservation tillage cotton. J. Econ. Entomol. 97: 1217–1232.

Tremelling, M., R. McSorley, and R. Gallaher. **2002**. Effects of winter cover crops on the soil surface invertebrate community, pp. 77–82. *In* Soil Crop Sci. Soc. Florida Proc. Soil Crop Science Soc., Florida, (c/o Univ Florida, Po Box 110290, Gainesville, FL, 32611-0290, USA).

Unger, P., and M. Vigil. **1998**. Cover crop effects on soil water relationships. J. Soil Water Conserv. 53**:** pp. 200-207**.**

USDA. **2015**. 2014 State Agriculture Overview. (http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MARYLAND).

Woltz, J. M., R. Isaacs, and D. A. Landis. **2012**. Landscape structure and habitat management differentially influence insect natural enemies in an agricultural landscape. Agric. Ecosyst. Environ. 152: 40–49.

Wortman, S. E., C. A. Francis, M. L. Bernards, R. A. Drijber, and J. L. Lindquist. **2012**. Optimizing cover crop benefits with diverse mixtures and an alternative termination method. Agron. J. 104: 1425–1435.

Young, O. P., and G. B. Edwards. **1990**. Spiders in United States field crops and their potential effect on crop pests. J. Arachnol. 18: 1–27.

Zhang, W., W. van der Werf, and S. M. Swinton. **2010**. Spatially optimal habitat management for enhancing natural control of an invasive agricultural pest: Soybean aphid. Resour. Energy Econ. 32: 551–565.