ABSTRACT

Title of Thesis: CAN COVER CROP RESIDUES SUPPRESS PESTS AND IMPROVE YIELD IN EGGPLANT?

Peter Coffey, Masters of Science, 2018

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Field studies were conducted over three growing seasons to investigate the effects of planting eggplant following three winter cover crop treatments on the abundance, predation, and colonization of Colorado potato beetle (*Leptinotarsa decemlineata*) and flea beetle (*Epitrix* spp.) abundance. Colorado potato beetle densities were observed to be significantly higher in the early season, and lower in the mid- and late- season when eggplant was planted into a crimson clover residue, compared with a crimson clover – rye mixture or bare ground control. Flea beetle abundance was significantly higher in treatments planted with a winter cover crop. Seedbed preparation treatments for weed control did not significantly affect pest abundance. These results contrast with previous research, raising new questions about how cover crop mixtures interact with pests, and how suppression methods influence the effects cover crops have on arthropod populations.

# CAN COVER CROP RESIDUES SUPPRESS PESTS AND IMPROVE YIELD IN EGGPLANT?

by

Peter Lawson Coffey

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University of Maryland, College Park, in partial fulfillment
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P. L. Coffey


## Abstract

Field studies were conducted over three growing seasons to investigate the effects of planting eggplant following three winter cover crop treatments on the abundance, predation, and colonization of Colorado potato beetle (*Leptinotarsa decemlineata*) and flea beetle (*Epitrix* spp.) abundance. Colorado potato beetle densities were observed to be significantly higher in the early season, and lower in the mid- and late- season when eggplant was planted into a crimson clover residue, compared with a crimson clover – rye mixture or bare ground control. Flea beetle abundance was significantly higher in treatments planted with a winter cover crop. Seedbed preparation treatments for weed control did not significantly affect pest abundance. These results contrast with previous research, raising new questions about how cover crop mixtures interact with pests, and how suppression methods influence the effects cover crops have on arthropod populations.


## Introduction

Diversifying field habitats can be a useful tool for manipulating soil, nutrients, beneficial arthropods, crop pests, and several other factors within agricultural ecosystems. For example, flowering borders can increase pollinators (Blaauw & Isaacs, 2014), beetle banks can promote predators (MacLeod *et al.*, 2004), and trap crops can prevent pests from reaching cash crops (Nielsen *et al.*, 2016). Interplanting non-host plants with crops can help suppress arthropod pests by slowing their immigration into fields (Hooks *et al.*, 2012), increasing predation rates (Patt *et al.*, 1997), and reducing oviposition (Theunissen *et al.*, 1995). Though pest suppression and enhanced yield are their primary goals, non-host plants may compete with cash crops for sunlight, water, nutrients and space (Teasdale & Mohler, 1993; Brandsæter *et al.*, 1998; den Hollander *et al.*, 2007; Lawley *et al.*, 2012). A potential strategy for mitigating competition is chemically or mechanically suppressing non-host plants prior to planting the cash crop. The plant residue remaining on the soil surface adds structural diversity to the field, and is less likely to compete with the cash crop.

In some systems, cover crops are incorporated into the soil as a green manure to add organic matter or nutrients into the soil. However, under conservation tillage systems, cover crops may be terminated and the residue remains on the field surface to suppress weeds (Teasdale *et al.*, 2007; Clark, 2013), provide refuge for predators (Blubaugh *et al.*, 2016), and inhibit insect pest establishment (Fleisher *et al.*, 2006). Though pairing cover crops with reduced or no-tillage practices has become a common practice in row crops such as corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.), this practice is less common in vegetable systems.

Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae), is widely regarded as the most important defoliator of potato and other solanaceous crops worldwide, including eggplant (*Solanum melongena* L.). It is challenging to manage due to its prodigious ability to quickly develop resistance to insecticides (See review by Alyokhin *et al.*, 2008). The United States grows approximately 64 million kg of eggplant annually, valued at $54 million (Thornsbury *et al.*, 2013), 98% of which is grown for fresh market (Naeve, 2014). In the Mid-Atlantic states, eggplant has an extended season and yields up to 15 harvests yearly, making it a consistent and reliable cash crop for fresh market production (Hamilton *et al.*, 1998). However, Colorado potato beetle can occur in high enough numbers to completely destroy eggplant plants (Hamilton *et al.*, 1998), and even low population levels can reduce eggplant flowering and yield (Cotty & Lashomb, 1982).

Crop rotation is often advised (Weisz *et al.*, 1994; Sexson & Wyman, 2005; Boiteau *et al.*, 2008), and is considered the most important cultural management tactic for Colorado potato beetle (Alyokhin *et al.*, 2008). However, many vegetable farms in the US are small with limited land (Macdonald *et al.*, 2013), and long distance crop rotation may not be a viable option (Dismukes *et al.*, 1997; Breuer *et al.*, 2006). Additionally, Colorado potato beetle is capable of prolonging its diapause for multiple years, which decreases the efficacy of crop rotation (Isely, 1935; Biever & Chauvin, 1990). This suggests other management tactics are needed.

The use of biological control is one potential management option for Colorado potato beetle suppression. *Podisus maculiventris* (Say) and *Perillus bioculatus* (Fabricius) (Hemiptera: Pentatomidae) are common stink bug predators that feed on Colorado potato beetle eggs, larvae, and adult stages. Both species are voracious predators and have successfully managed Colorado potato beetle when released in small experimental plots of potatoes (Hough-Goldstein & Keil, 1991; Khloptseva, 1991; Biever & Chauvin, 1992; Cloutier & Bauduin, 1995; Hough-Goldstein & McPherson, 1996; Hough-Goldstein *et al.*, 1996). Despite their efficacy, rearing and releasing these predators can be difficult and costly. Both species are also common in Northeastern states, but natural populations rarely reach levels required to manage Colorado potato beetle early in the season.

Diversifying field habitats by adding straw mulches to the soil surface can effectively reduce Colorado potato beetle numbers (Zehnder & Hough-Goldstein, 1990; Brust, 1994) and the damage they cause in potato (*Solanum tuberosum* L.) fields (Stoner *et al.*, 1996). However, few studies have examined this tactic in eggplant (Stoner, 1997). In addition, adding straw mulch to the field system is an additional cost to growers, and may not be feasible when it involves large crop acreage. Cover crop residues may be a more economically viable method of increasing diversification than purchasing straw, as many producers already grow cover crops as a part of their production practices. However, cover crop suppression and termination practices may also create additional input and labor costs. As such, growers need to know the potential costs and benefits of using cover crop residues to select the best management options.

Several studies evaluated the use of habitat diversification to manage Colorado potato beetle, and reported reductions in their abundance and movement into fields because of reduced host plant apparency (Lashomb & Ng, 1984; Zehnder & Hough-Goldstein, 1990; Stoner, 1997; Szendrei *et al.*, 2009). A recent study that investigated the impact of planting eggplant into a senescing crimson clover (*Trifolium incarnatum* L.) cover crop showed delayed colonization of Colorado potato beetle and reduced population abundance compared to monoculture plantings (Hooks *et al.*, 2012). Only a few studies have investigated changes in Colorado potato beetle predator densities in response to diversification (Horton & Capinera, 1987; Brust, 1994; Hooks *et al.*, 2013), and none have looked specifically at cover crop residue. Results of previous studies on habitat diversification have been mixed, suggesting that its effects may differ according to cropping systems, non-host plants, and community of arthropods (Root, 1973; Rypstra *et al.*, 1999; Blubaugh *et al.*, 2016).

In addition to Colorado potato beetle, flea beetles (*Epitrix* spp., Coleoptera: Chrysomelidae) are economically important pests of eggplant, and in sufficient numbers can defoliate eggplant seedlings within 24 hours (Andersen, 2011; Bunn & Murray, 2015). Eggplant (*Epitrix fuscula* Crotch), potato (*Epitrix hirtipennis* (Melsheimer)), and tobacco (*Epitrix cucumeris* (Harris)) flea beetles are pests of eggplant, and often occur together in Maryland (Parker & Snyder, 2016; Sorensen & Baker, 2016). Most research into flea beetle management has focused on chemical control methods (Mcleod *et al.*, 2002). However, chemical options are limited, particularly in organic systems (Patton *et al.*, 2003), suggesting that alternative management practices are needed. Habitat diversification with legume cover crops may provide effective pest management strategies to producers with flea beetle problems. Studies have showed that leguminous cover crops can reduce flea beetle numbers on eggplants (Hooks *et al.*, 2012) and other crops (Altieri *et al.*, 1985; Garcia & Altieri, 1992). However, their use as cover crop mixtures has not been studied.

This study expands the previous work by Hooks et al., (2012) in which eggplant was interplanted into a crimson clover dying mulch. In that study, competition between the crimson clover dying mulch and eggplant plants resulted in significantly lower yield during one study year. In addition, as the crimson clover senesced its ability to prevent weed establishment lessened. The objective of this study is to evaluate and compare a crimson clover cover crop with a crimson clover and rye (*Secale cereal* L.) cover crop mixture and their respective impacts on eggplant associated arthropods as a surface residue. When used as a surface residue, the cover crop is less likely to compete with eggplant plants. Further, rye and other cereal cover crops have a relatively high carbon-to-nitrogen ratio (C:N ~33:1), which slows decomposition, prolonging physical interference with weeds (Creamer *et al.*, 1997). In contrast, crimson clover and other legumes fix nitrogen and have a relatively low C:N (~15:1). Nitrogen fixed by legume cover crops can improve yield (Miguez & Bollero, 2005), but they decompose rapidly decreasing their interference with weeds (Manzoni *et al.*, 2008). Thus, in addition to its potential to manipulate insects, using a crimson clover-rye mixture could lead to greater weed suppression than crimson clover alone. Farmers in Maryland can be reimbursed for growing crimson clover as a winter cover crop if it is mixed with a cereal grain (Maryland Department of Agriculture, 2017). This research was conducted as part of a larger experiment which examined pre-planting seedbed techniques for enhanced weed suppression as well as insect pest management.

Cover crops grown in mixtures can provide a variety of other desirable traits, including increased biomass accumulation, structural diversity, and predator habitat and abundance (Fleisher *et al.*, 2006; Woodcock *et al.*, 2007; Poffenbarger *et al.*, 2015). Thus, it is hypothesized that insect pest suppression can be enhanced by planting eggplant into residue from a crimson clover-rye cover crop mixture compared to eggplant planted into sole crimson clover residue or bare-ground. Specifically, it is predicted that the densities and feeding injury of Colorado potato beetle and flea beetles will be higher and occur earlier in the eggplants planted into fallow ground compared to eggplants planted into a cover crop residue. Secondly, pest abundance will be suppressed more in mixed cover crop residue compared to a single-species cover crop. Additionally, predator densities and Colorado potato beetle egg mortality will be higher in the mixed cover crop compared to fallow treatment.

## Methods

### *Experimental design*

Studies were conducted during 2014, 2015, and 2016 in fields that followed field corn at the Central Maryland Research and Education Center (CMREC) in Upper Marlboro, Maryland (38.861449, -76.776148). In 2016, an additional study was conducted at the Western Maryland Research and Education Center (WMREC) in Keedysville, Maryland (39.510898, -77.735801). Each experiment was laid out as a randomized complete block split plot design with each treatment replicated four times. Plots consisted of three cover crop treatments: 1) crimson clover, *Trifolium incarnatum*

L. (herein referred to as 'clover'), 2) a mixture of crimson clover and rye, *Secale cereale* L., (herein referred to as 'mixed'), and 3) a no-cover crop fallow control (herein referred to as 'fallow'). The two subplot treatments, included as part of a larger study, consisted of two weed control methods: 1) strip tillage just prior to transplanting the eggplant (ST) and 2) stale seedbed (SS) in which the strip tillage was conducted several weeks before planting and the tilled strip treated with an herbicide just prior to eggplant transplanting. These weed control methods did not significantly affect arthropod abundance. Table 1 gives the schedule of field plot activities for each experiment.

In the fall preceding each study year, cover crops were seeded at rates of 25.8 kg/ha in the clover, and 14.6 kg/ha clover and 72.9 kg/ha rye in the mixed treatment. Treatment plots were 12.2 m by 11.9 m, and separated by 9.1 m alleys, which were planted with rye at a rate of 135.6 kg/ha. Alleys were flail mowed to terminate the rye and subsequently mowed as needed throughout the season. Each whole plot was prepared to accommodate 11 rows of eggplant, with four rows in each subplot, a buffer row at each plot edge, and one buffer row between subplots (Fig. 1). In 2014 and 2015, all plots were flail mowed when the rye reached the mid-anthesis stage, and then strip tilled in the ST subplots. In 2016, ST subplots were strip tilled before the cover crop was terminated. All SS subplots were tilled at least two weeks prior to transplanting to allow weed seeds to germinate (Table 1), after which a banded spray of Avenger® herbicide (d-limonene, Avenger Organics, Buford, Georgia) was applied to the tilled rows with a Demco® 40 Gallon Pro Series Sprayer (Demco Manufacturing Co., Boyden, Iowa) to kill weed seedlings. All ST subplots were tilled on the same day that herbicides were applied to SS subplots. Rows were tilled with a Bigham® Ag strip tiller (Bigham Brothers Inc., Generation 3, model #789-222, Lubbock TX), except in 2014 when ST subplots were rototilled (Craftsman® 4-cycle Mini Tiller, KCD IP, LCC, Hoffman Estates IL). Each method produced tilled rows 20 cm wide separated by 83 cm of untilled inter-row.

Eggplant were sown at the University of Maryland Research Greenhouse in 48 $mm^2$ plug flats with standard potting soil and were transplanted in the field approximately 8 weeks later. In 2014 and 2015, the variety 'Nubia' was planted; however, this variety was unavailable in 2016. As such, the variety 'Clara' was selected as a replacement (both from Johnny's Selected Seeds®, Winslow, ME). Eggplants were transplanted using a hand-held transplanter (Stand 'n Plant®, Saltsburg PA) in early summer (Table 1). Thirteen plants were planted in each row spaced 91 cm apart, for a total of 143 plants per whole plot (44 per subplot, 55 in the three buffers). As needed, natural rainfall was supplemented with drip irrigation with 30 cm spacing, and calcium nitrate fertilizer (15.5-0-0) was applied twice per season around the base of each plant. In 2014, a total of 9.4 kg N/acre was applied according to the methods of previous studies by Hooks *et al.* (2012, 2013). However, in 2014 plants showed signs of nitrogen deficiency, so in 2015 and 2016, fertilizer input was increased to the recommended 56.7 kg N/acre (Wyenandt *et al.*, 2016). Weeds were managed by hand weeding, except at CMREC in 2016 when weed pressure was very high, and weeds were managed between rows with a rototiller.

*Insect counts*

One week after transplanting, visual plant inspections were initiated to assess densities of Colorado potato beetle, flea beetles, and predatory stink bugs. Colorado potato beetles and predaceous stink bugs (two-spotted stink bug and spined soldier bug) were counted according to their life stage (egg masses, larvae/nymphs, and adults). Flea beetles were counted as adults only. For all insect counts, visual inspections were made on all non-buffer plants, and the total number of insects was recorded for each subplot (**Error! Reference source not found.**). Insect counts were conducted every seven days for eight weeks, at which time harvest began. Flea beetles are a primary concern in the early season, when heavy infestations can stunt or kill seedlings (Mcleod *et al.*, 2002; Bunn & Murray, 2015), thus, counts were conducted during the first four weeks after planting. Flea beetle infestation on young plants reached densities that would significantly stress plant growth and confound the experiment, and so a rescue treatment of Entrust was applied on 10 June 2016 at both sites.

*Colorado potato beetle egg mortality*

Colorado potato beetle egg masses were collected from a nearby untreated potato field and placed in each subplot to measure egg mortality on three dates during 2014. The number of eggs per mass was recorded and then they were attached on the underside of mature eggplant leaves and secured with paperclips approximately 10 cm above the ground, which is where the majority of Colorado potato beetle egg masses are deposited. On each occasion, four egg masses were placed individually on plants spaced uniformly within each plot. After three days of exposure, egg masses were collected and numbers of live (unhatched and intact, or successfully hatched) and dead (eggs destroyed by chewing or sucking predators) eggs on each mass were recorded. In 2015 and 2016 sentinel egg masses were not deployed, and naturally-occurring egg masses found on eggplants were monitored to measure mortality. To do this, the first four egg masses located during each weekly insect count were marked with flagging tape, the number of eggs was recorded and each egg mass was monitored every two days until all eggs successfully hatched or were consumed by predators.

*Defoliation*

The 3rd, 6th, and 9th plants in each row were examined each week (**Error! Reference source not found.**) to visually estimate the level of defoliation as a result of chewing herbivores (primarily Colorado potato beetle). Defoliation expressed as the percentage of total leaf area missing to the nearest 5% was independently estimated by 2-4 independent observers for each plant, and averaged over the entire plot. Additionally, the feeding injury of flea beetles was recorded as the number of “shot” holes observed on the youngest mature leaf of each plant. In 2016, extensive injury due to high numbers of flea beetles made counting shot holes in an entire leaf impractical, so the number of holes in a $60cm^2$ section of the leaf center was recorded. The number of shot holes was recorded as a total per plot.

*Marketability*

When fruit reached marketable size, harvesting began and continued weekly or twice weekly as necessary until plants were frost killed or no longer producing mature fruit (a harvest period of approximately two months). Each fruit was rated as marketable or culled because of insect damage, and the total number of marketable and culled fruit in each subplot was recorded. Fruit from buffer plants was also harvested, but not included in the data collection.

**Data analysis**

For all univariate analyses, assumptions of normality of data and homogeneity of variance were first evaluated using the Shapiro-Wilk *W* test (SAS Institute, Version 9.4) and by examining for nonrandom patterns in residual plots. The square root transformation was performed prior to analysis to correct for skewness and heterogeneous variances of count data, and back-transformed means were presented for summarization. Weed control subplots were included in initial models, but did not significantly affect data for any variable (Colorado potato beetle life stage, flea beetles, predatory stink bugs, defoliation and shot holes, and egg mortality; $P > 0.05$), and so data from both subplots was combined and analyzed as averages per plot within each replicate and week. Because of low abundance early in the season, Colorado potato beetle larval counts from sampling weeks 1-3 and stink bug counts for weeks 1-4 were excluded from analysis. Flea beetles occurred in very low numbers in 2014 and 2015, but were very abundant at both sites in 2016, so only counts from 2016 were included in the analysis. Additionally, because of low abundance, counts of adults and nymphs of two spotted stink bug and spined soldier bug were combined and analyzed as total predatory stink bugs.

A mixed model analysis of variance (Proc Mixed: SAS Institute) was used to test for treatment and interaction effects on each measured variable. Cover crop treatment and sampling week were treated as fixed factors, whereas replicates and year were treated as random block effects. In all analyses, the repeated measures option was used with the most appropriate covariance structure to correct for correlated data over sampling time.

Significant effects among means were separated using Tukey's adjustment for pairwise comparisons ($P \leq 0.05$).

**Results**

*Insect populations and egg mortality*

Broadly, densities of Colorado potato beetle were low until 3-4 weeks after planting when they rapidly increased, peaking in the midseason, and then slowly declining through the growing season. Abundance of adult Colorado potato beetle showed a significant interaction between sampling week and cover crop treatment ($F_{(14, 72)}$=2.78, $P$ = 0.002), with a higher abundance of adults in the crimson clover than the mixed or fallow treatments early in the season, a trend which was reversed in the later season (Fig. 2). This interaction effect was not observed in the abundance of Colorado potato beetle eggs or larvae. However, there was a significant main effect of cover crop treatment on counts of both eggs and larvae. Eggs were significantly more abundant in the mixed than fallow treatment, with clover being intermediate ($F_{(2,72)}$=4.24, $P$=0.018). Larvae were significantly more abundant in the mixed and fallow treatments than in the clover ($F_{(2,42)}$ = 4.55, $P$=0.016, Fig. 3). Flea beetle abundance in 2016 was not affected by an interaction between date and treatment. However, there was a significant main effect of cover crop treatment ($F_{(2,33)}$=16.18, $P < 0.001$). Higher counts were detected in the crimson clover and mixed than in the fallow treatment (Fig. 3). Abundance of predatory stink bugs showed a significant interaction between cover crop treatment and date ($F_{(14,69)}$=2.63, $P$ = 0.004), which was highly variable, showing a switch from the mixed treatment to the clover at the end of the season.

*Leptinotarsa decemlineata* egg mortality was not affected by an interaction effect, or a main effect of cover crop treatment (*P* > 0.05). In 2015 and 2016 a total of 638 naturally occurring egg masses were located, of 473 were relocated and fates determined. Of the eggs in all three years whose fate could be determined, 51% hatched successfully, with predation distributed between chewing (24%) and sucking (25%) predators. Mean egg mass size was 31.4 eggs, and the majority of egg masses were either completely successful at hatching or completely predated.

*Defoliation, and Insect Damaged Fruit*

Observationally, stink bugs and big-eyed bugs (*Geocoris* spp.) were the most commonly observed sucking predators, with lady beetles (Coccinelidae) being the most commonly observed chewing predators. Fruit damage was primarily observed to be caused by lepidopteran pests, which were not differentiated by species. Saltmarsh caterpillar, *Estigmene acrea* (Drury), and the white lined sphinx moth, *Hyles lineata* (Fabricius), were commonly observed feeding on fruits.

Overall there was no significant main or interaction of cover crop and date (P > 0.05) on Colorado potato beetle defoliation, number of flea beetle shot holes, or proportion of fruit culled due to insect damage. Mean harvest per plant was 1.14 kg, or 9,469.3 kg/ ha, of which 27% of fruit were culled, primarily due to heavy surface scarring, resulting in a marketable yield of 6,912.6kg/ha, within the expected yield for eggplant (3,023.6-7,305.8kg/ha) depending on row spacing and variety (Santos, 2008; Lewis W. Jett, 2018).

**Discussion**

While results of this study confirm that cover crop residues can affect pest and beneficial insect densities in eggplant fields, the cereal cover crop mixture did not increase pest numbers as predicted. Pest abundances were variable between years and locations, with Colorado potato beetle occurring in large numbers in 2014, and very low numbers in 2016. Flea beetles only occurred in high numbers in 2016, when abundance passed economic threshold and required a rescue insecticide application. Overall, flea beetle numbers were significantly lower in the fallow treatment, but shot hole damage was not different among treatments. Flea beetles overwinter in the soil (Garcia & Altieri, 1992; Bunn & Murray, 2015) so it's possible the cover crops provide advantages to overwintering survival similar to that seen in beneficial beetle species (Landis *et al.*, 2000; MacLeod *et al.*, 2004; Pywell *et al.*, 2005). However, flea beetles are highly mobile, and it's unlikely their distribution is driven only by overwintering success. Microclimate has been shown to be a driver of flea beetle distribution (Tahvanainen, 1983; Bach, 1993), and so temperature and moisture effects of the cover crop mulches may provide a more attractive microclimate, particularly in the middle of the day when sampling was occurring.

Predatory stink bug abundance was very low, particularly in the early season, and never approached the threshold reported to provide economic control in potatoes (Tamaki & Butt, 1978; Hough-Goldstein & Keil, 1991; Hough-Goldstein & McPherson, 1996; Hough-Goldstein *et al.*, 1996). There was a significant interaction between treatment and date in the late season, however, Colorado potato beetle abundance declined steadily in the late season, so any treatment effect on predator populations is unlikely to play an important role in their management. There are a variety of insects that prey on Colorado potato beetle eggs and larvae (Hilbeck & Kennedy, 1996; Hilbeck *et al.*, 1997). However, egg predation was unaffected by treatment, suggesting that it is unlikely that predators were the primary cause of differences in Colorado potato beetle abundance between treatments.

Adult Colorado potato beetle abundance was highest in the crimson clover treatment in the early season relative to either the mixed (crimson clover and rye) or fallow treatments, suggesting that movement into those plots was accelerated, not delayed as was predicted. This contrasts with previous research, and may be a result of flail mowing in this study, which creates a fine residue. Previous research used rolled or dying cover crops (Hunt, 1998; Hooks *et al.*, 2012), which leaves greater vegetation. Mowing may have reduced the structural complexity of the residue subsequently, removing the physical barrier which authors suggested inhibited Colorado potato beetle movement into plots in previous studies. Additionally, the mowing may have accelerated the decomposition of the clover residue, resulting in an early season nitrogen flush, temporarily increasing the attractiveness of plants in that treatment. Although early-season leaf nutrients were not assessed in this study, nitrogen fertilization can affect plant semiochemical production and can increase insect feeding damage (Haukioja *et al.*, 1985; Lu *et al.*, 2007; Veromann *et al.*, 2013), and Colorado potato beetle has been well documented to respond to host volatile production (Visser & Avé, 1978; Landolt *et al.*, 1999; Dickens, 2000, 2002). It’s possible that early season nitrogen from the mowed crimson clover temporarily increased plant attractiveness, and the slower release of nitrogen in the mixed treatment made it more attractive several weeks after planting when females began selecting oviposition sites, leading to higher egg mass numbers in the mixed treatment than the clover treatment. Nitrogen dependent plant volatiles affecting oviposition may also explain why egg masses were the least abundant in the fallow treatment, which received no nitrogen benefit from a cover crop. However, nitrogen effects on pests may be non-linear (Veromann *et al.*, 2013), and plant volatiles and induced defenses are complex, plastic, and may be antagonistic (Karban *et al.*, 1999; Rasmann & Agrawal, 2009).

Significantly lower numbers of Colorado potato beetle larvae in the clover treatment reinforce the findings of (Hooks *et al.*, 2012), however, the mechanism is still unknown. Neither predator numbers nor physical characteristics of the residue apparently explain this difference. Research in potatoes suggests that some cultivars have resistance to Colorado potato beetle herbivory (Yas¸ar & Güngör, 2005; Fathi *et al.*, 2013). Similar defense mechanisms have been observed in eggplant with other pests (Lal, 1991), and resistance mechanisms can be affected by both fertilization and herbivory (Shaner & Finney, 1977; Mutikainen *et al.*, 2000; Gomes *et al.*, 2005), so extra early season nitrogen from the crimson clover, or early season herbivory from overwintering Colorado potato beetle adults, may have decreased the attractiveness of this treatment as an oviposition sites, resulting in fewer larvae in the late season.

Mixed species residues can also be subject to synergistic or antagonistic effects on decomposition over time as a result of litter chemical traits, such as lignin:N ratio, tannins, and total phenols (Meier & Bowman, 2010; Chen *et al.*, 2015). Rye was selected as the cereal crop in this study because it has been shown to suppress Colorado potato beetle numbers in other crops (Hunt, 1998; Szendrei *et al.*, 2009), but if the causal factors leading to the lack of suppression can be identified then perhaps an alternative cereal can be identified as a viable potential component of a crimson clover mixture. Currently, Maryland farmers can be reimbursed for planting legume cover crops only if they are planted in a mixture with a cereal grain (Maryland Department of Agriculture, 2017), so growers would need to weigh the benefits of Colorado potato beetle suppression provided by crimson clover alone against the monetary gain provided by the cost share program.

Taken together, results of this study provide more evidence that cover crop residues can affect Colorado potato beetle populations in eggplant crops. As seen in previous studies, the crimson clover residues were effective at suppressing Colorado potato beetle populations. However, in contrast with previous research, a delay in colonization was not observed. Moreover, the lack of suppression provided by the mixed treatment residues, raises additional questions. More research is required to determine the causes of the pest suppression provided by crimson clover, and to investigate different practices for terminating cover crops prior to or after strip tillage and their effects on pest suppression in the cash crop. This work is necessary to determine the costs and economic benefits of using cover crop residues to suppress pest numbers.

## Tables and Figures

| Field Site/Year | Cover Crop Planting | Eggplant Seeded in Green House | Cover Crop Terminated | Stale Seedbed (SS) Subplots Strip-Tilled[a] | Strip-Tilled (ST) Subplots Strip-Tilled[b] | Eggplant Transplanted |
|---|---|---|---|---|---|---|
| CMREC 2014 | 1 Oct 2013 | 18 April 2014 | 12 May 2014 | 12 May 2014 | 6 June 2014 | 10 June 2014 |
| CMREC 2015 | 2 Oct 2014 | 21 April 2015 | 22 May 2015 | 26 May 2015 | 15 June 2015 | 16 June 2015 |
| CMREC 2016 | 22 Sep 2015 | 18 April 2016 | 27 May 2016 | 26 April 2016 | 30 May 2016 | 31 May 2016 |
| WMREC 2016 | 23 Sep 2015 | 18 April 2016 | 1 June 2016 | 16 May 2016 | 1 June 2016 | 2 June 2016 |

Table 1. [a]Herbicide was applied to strip-tilled zones in SS subplots prior to transplanting the eggplant. Note that in 2014 and 2015 the SS plot was tilled immediately after the cover crop was terminated, but in 2016 it was tilled 2 and 4 week before cover crop termination at WMREC and CMREC, respectively. [b]The ST subplots were strip-tilled just prior to transplanting the eggplant.

| | Crimson Clover | Fallow | Mixed |
|---|---|---|---|
| Colorado Potato Beetle Defoliation (%) | 7.6 ± 0.3 | 7.3 ± 0.2 | 7.5 ± 0.2 |
| Flea Beetle Shot Holes per Leaf (2016) | 135.5 ± 4.8 | 153.7 ± 7.0 | 143.5 ± 6.0 |
| Proportion of Fruit Culled Because of Insect Damage (%) | 25.6 ± 4.1 | 29.3 ± 5.5 | 26.9 ± 5.8 |

Table 2. Mean insect damage to eggplant plants across sites and years (±SE), were not significantly different ($P > 0.05$) between the crimson clover, fallow, or crimson clover-rye (mixed) cover crop treatments  Shot holes from flea beetle feeding were only analyzed in 2016 when the populations were high enough to cause economic damage.

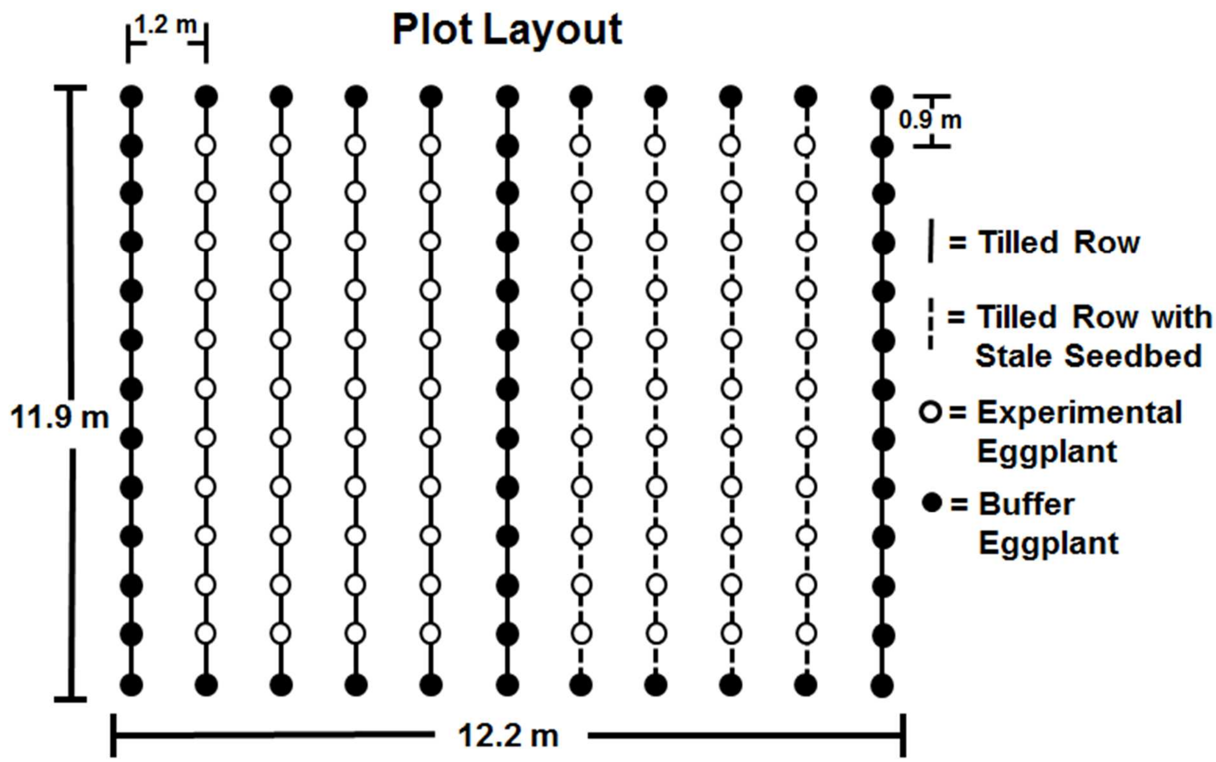



Figure 1. Eggplant whole plot design. Each whole plot received one of three cover crop treatments, and half of each whole plot treatment (randomized, left or right) received a herbicide application in strip tilled zones as part of the stale seedbed technique, and the other half was not treated with a herbicide.

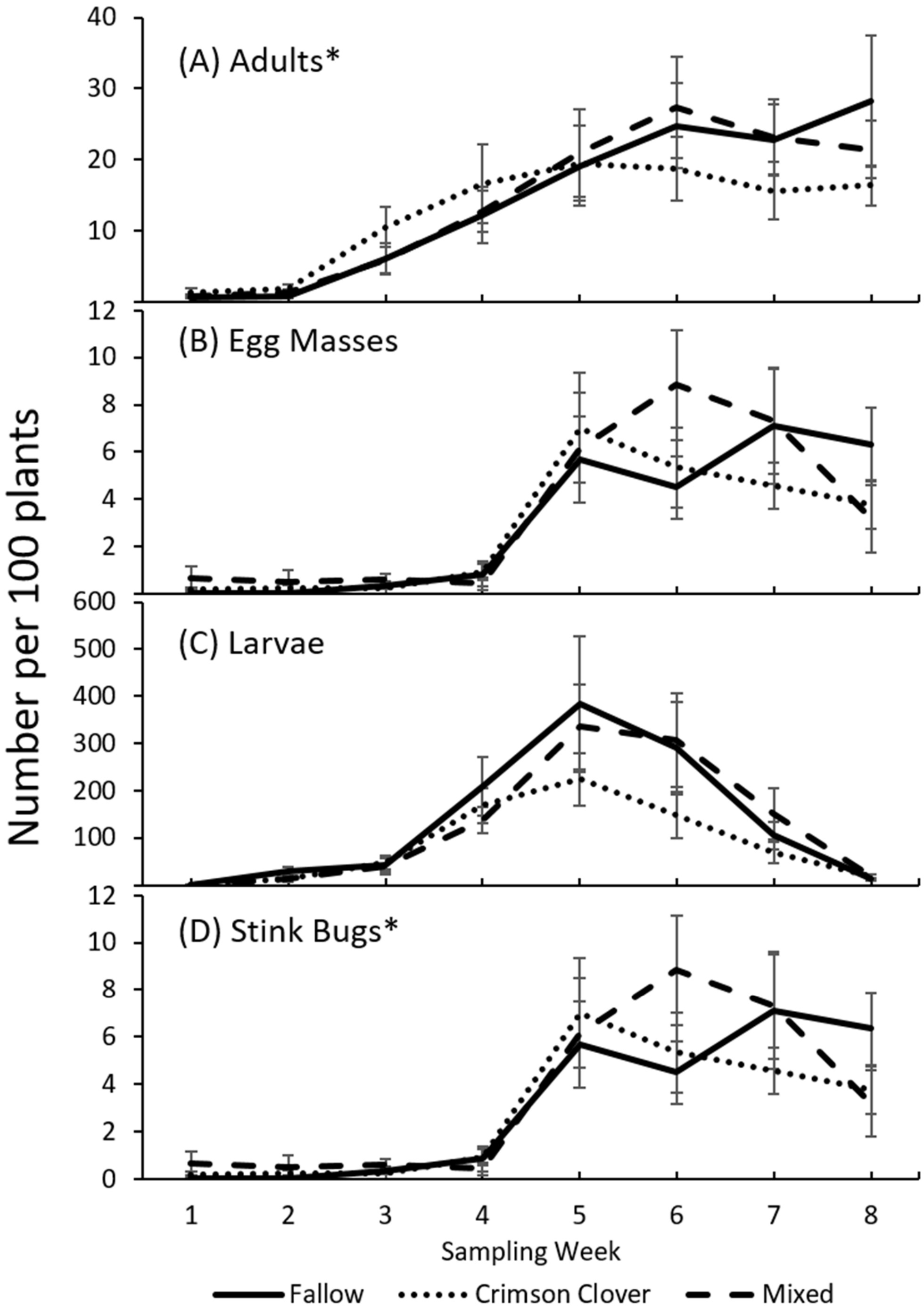
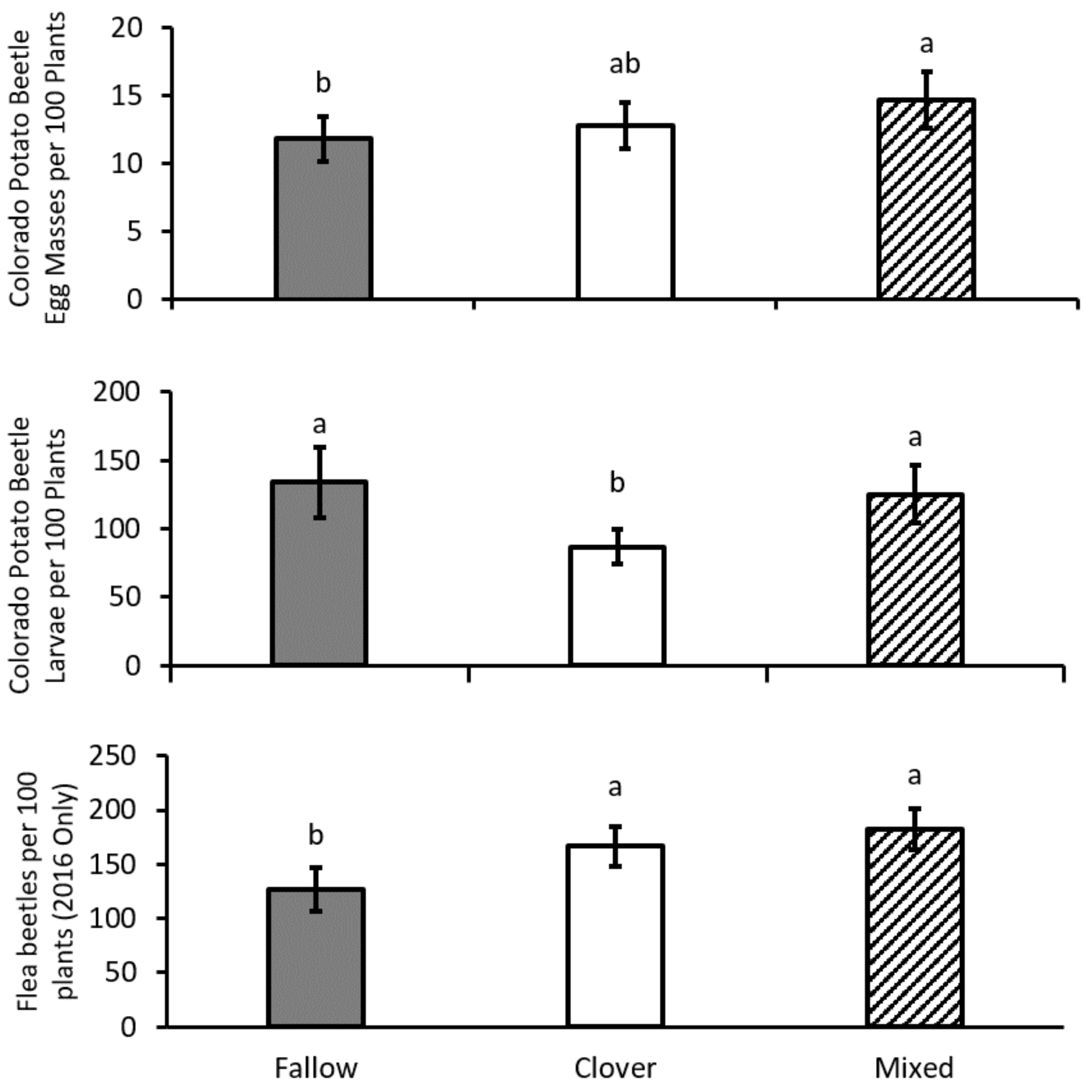



Figure 2. Back-transformed means (± SE) abundance of Colorado potato beetle adults, egg masses and larvae, and predatory stink bugs (both two-spotted stink bug and spined soldier bug) per 100 plants during each sampling week across all sites and years in three different cover crop treatments, a crimson clover residue (clover), a crimson clover-rye mix (mixed), and a no cover crop control (fallow). Counts from stink bugs prior to week 5 and Colorado potato beetle larvae prior to week 4 were excluded from analysis. Significant interactions between sampling week and cover crop treatment were observed in Colorado potato beetle adults and predatory stink bugs (indicated with a *).




*Figure*

Figure 3. Back-transformed mean (± SE) abundance of Colorado potato beetle egg masses and larvae, and flea beetles across the growing season in three different cover crop treatments, crimson clover residue (clover), a crimson clover-rye mix (mix) and a no-cover crop control (fallow). Different letters indicate significant differences between cover crop treatments.

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