

# Reflective Polyethylene Mulch Reduces Mexican Bean Beetle (Coleoptera: Coccinellidae) Densities and Damage in Snap Beans

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## Abstract

Mexican bean beetle, *Epilachna varivestis* Mulsant, is a serious pest of snap beans, *Phaseolus vulgaris* L., in the eastern United States. These beetles are intolerant to direct sunlight, explaining why individuals are typically found on the undersides of leaves and in the lower portion of the plant canopy. We hypothesized that snap beans grown on reflective, agricultural polyethylene (plastic mulch) would have fewer Mexican bean beetles and less injury than those grown on black plastic or bare soil. In 2014 and 2015, beans were seeded into beds of metallized, white, and black plastic, and bare soil, in field plots near Blacksburg, VA. Mexican bean beetle density, feeding injury, predatory arthropods, and snap bean yield were sampled. Reflected light intensity, temperature, and humidity were monitored using data loggers. Pyranometer readings showed that reflected light intensity was highest over metallized plastic and second highest over white plastic; black plastic and bare soil were similarly low. Temperature and humidity were unaffected by treatments. Significant reductions in Mexican bean beetle densities and feeding injury were observed in both metallized and white plastic plots compared to black plastic and bare soil, with metallized plastic having the fewest Mexican bean beetle life stages and injury. Predatory arthropod densities were not reduced by reflective plastic. Metallized plots produced the highest yields, followed by white. The results of this study suggest that growing snap beans on reflective plastic mulch can suppress the incidence and damage of Mexican bean beetle, and increase yield in snap beans.

**Key words:** *Epilachna varivestis*, snap bean, cultural control, reflective plastic mulch, light intensity

Mexican bean beetle, *Epilachna varivestis* Mulsant, is an herbivorous lady beetle (Coleoptera: Coccinellidae) that feeds of many legumes (Fabaceae). Since 1920, when it was first discovered in the eastern United States (Howard 1924), Mexican bean beetle has achieved economic pest status primarily on snap beans, *Phaseolus vulgaris* L., lima beans, *Phaseolus lunatus* L., and to a lesser extent, soybeans, *Glycine max* (L.) Merr. (Capinera 2001, Nottingham et al. 2016). Although Mexican bean beetle is found throughout the United States, it is most common and severe in the Mid-Atlantic and southern Appalachian Mountain regions (Nottingham et al. 2016). Adults and larvae use chewing mouthparts to dislodge tissue from leaves and pods, then compress the tissue to extract and consume plant juices (Howard 1941). Excessive feeding on leaves reduces the plant's photosynthetic potential and promotes desiccation, which can result in yield losses (Capinera et al. 1987, Nolting and Edwards 1989, Barrigossi 1997, Peterson et al. 1998). In addition, direct feeding on pods creates unsightly scars that render the crop unmarketable and more susceptible to fruit-rotting pathogens (Nottingham et al. 2016).

Many labeled insecticides provide effective control of Mexican bean beetle (Nault and Speese 2001, Patton et al. 2003, Kuhar et al. 2012, Nottingham et al. 2015), and resistance to the common groups used in vegetable production (neonicotinoids and pyrethroids) has not been documented. In the Mid-Atlantic and southern Appalachian Mountain regions of the United States, where Mexican bean beetle outbreaks are most common, snap bean production usually occurs on a small- to medium-sized farm scale, and often in organic systems. Small- to mid-sized producers are more likely to employ nonchemical methods for pest control, than are large-scale producers (Aselage and Johnson 2009). Considering the farming culture in regions with Mexican bean beetle, and the increasing market for organic and chemical-free produce, it is important that alternative management strategies are scientifically evaluated for this pest.

The most widely used nonchemical option for managing Mexican bean beetle is augmentative biological control, using a small parasitoid wasp, *Pediobius foveolatus* (Crawford) (Hymenoptera: Eulophidae). Inoculative releases can successfully

reduce local populations of Mexican bean beetle by attacking and killing the larval stage (Angalet et al. 1968, Stevens et al. 1975, Barrows and Hooker 1981, Fess 2008). Unfortunately, these exotic parasitoids must be released annually due to their inability to overwinter in temperate climates (Stevens et al. 1975, Ghani and Mohyuddin 1982, Schaefer et al. 1983). Cool and wet weather is optimal for Mexican bean beetle, but problematic to *P. foveolatus* (Marcovitch and Stanley 1930, Auclair 1960, Stevens et al. 1975, Gale and Shepard 1978, Wilson et al. 1982, Mellors and Bassow 1983, Stoner 2002); therefore, wasps may fail to manage this pest in some seasons.

Other than biological control, few nonchemical methods exhibit adequate control of Mexican bean beetle (Capinera 2001, Fess 2008, Nottingham et al. 2016). Cultural management, which is a fundamental component of integrated pest management (IPM), uses strategic crop production practices that reduce the likelihood of damaging pest outbreaks (Zehnder et al. 2007). Two of the most common cultural strategies in agriculture, field sanitation and crop rotation, are ineffective at reducing injury from Mexican bean beetle (Capinera 2001), because adults are capable of flying over 11 km after emerging from their overwintering sites, which are usually wooded areas away from crop fields (Howard and English 1924, Thomas 1924, Friend and Turner 1931, Auclair 1960).

Developing a successful cultural management strategy often requires the diagnosis and exploitation of a specific limiting factor. Research by Miller (1930) and Howard and English (1924) demonstrated that Mexican bean beetle is highly sensitive to direct light. Miller (1930) reported that adults and larvae became restless and absconded into shaded areas of the plant canopy when exposed to direct light. When forced to remain in direct light, mortality of eggs, larvae, pupae and adults increased (Howard and English 1924, Miller 1930). These findings probably explain why all life stages of Mexican bean beetle are typically found on the undersides of leaves, or in the lower portion of the plant canopy (Howard 1924, Barrigossi et al. 2001, Nottingham et al. 2016).

Because Mexican bean beetle is adversely affected by direct light, it may be possible to suppress populations and injury by planting snap beans on reflective, agricultural polyethylene (plastic mulch). Plastic mulch is commonly used for weed control, manipulating soil temperature and reducing soil-water evaporation (Lament 1993). Black plastic mulches are common in vegetable agriculture, because they increase soils temperatures by absorbing short wavelength light (400–700nm); while light-reflecting mulches, such as metallized (aluminum-infused top, black bottom) and white (white top, black bottom), keep soil temperatures cool, making them more conducive for cooler weather crops (Ham et al. 1993, Lament 1993). Highly reflective mulches (those with aluminum or silver infused surfaces) have been shown to effectively mitigate injury and/or disease transmission from a wide variety of insects, including aphids (Aphididae), thrips (Thripidae, Phlaeothripidae), whiteflies (Aleyrodidae), cucumber beetles (Chrysomelidae), leafhoppers (Cicadellidae), leaf miners (Agromyzidae), and plant bugs (Miridae) (Chalfant et al. 1977; Wells et al. 1984; Scott et al. 1989; Kring and Schuster 1992; Cszinszky et al. 1995; Caldwell and Clarke 1999; Rhains et al. 2001; Summers and Stapleton 2002a, b). Wells et al. (1984) determined that, in addition to having fewer potato leafhoppers, *Empoasca fabae* (Harris) (Hemiptera: Cicadellidae), snap beans planted on reflective mulch were larger and produced higher yields than plants grown on bare soil. However, not all insects are controlled by this method. Stoner (1997) found that colonization and development of Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae), was unaffected by

reflective plastic, and Schalk and Robbins (1987) witnessed increased incidence and injury of tomato pinworm, *Keiferia lycopersicella* (Walshingham) (Lepidoptera: Gelechiidae), and tomato fruitworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae).

The purpose of this study was to determine if planting snap beans on metallized plastic or white plastic would reduce Mexican bean beetle densities and concomitant damage to snap beans. Predatory arthropods were also sampled to evaluate treatment effects on natural enemies. Temperature, humidity, and reflected light intensity (RLI) were monitored over each treatment to quantify differences in these environmental conditions, and to test their impact on insect abundance.

## Materials and Methods

### Experimental Design

Experiments took place at Virginia Tech's Kentland Farm in Whitethorne, VA. Three experiments were conducted, one in the summer of 2014, and two in the summer of 2015. In all experiments, 'Dragon's Tongue' snap beans were grown on four treatments: 1. "Metallized" plastic: aluminum-infused top and black bottom (Sunup Reflective Films, Oceanside, CA); 2. "White" plastic: white top and black bottom (Berry Plastics, Evansville, IN); 3. "Black" plastic: black top and black bottom (Berry Plastics); and 4. bare soil. Mulches were purchased from Harris Seeds, Rochester, NY. Treatment and control beds were formed by a tractor-pulled plastic layer. Plastic edges were buried by hand. One row of beans was grown per plastic bed. Adjacent beds were separated by 2 m of fallow soil. Seeding holes, 7 cm diameter, were cut into beds 35 cm apart, and two bean seeds were directly seeded per hole (two bean plants grown together will be called a "cluster"). Beans were drip irrigated twice a week from planting to harvest. Glyphosate (1.2 kg Al/ha Roundup Ultra Max; Monsanto, St. Louis, MO) was applied between rows as needed to control weeds. Weeds between bean plants in bare soil plots were removed by hand weekly.

### 2014 Experiment

Beans were planted on 17 June 2014. Plots were arranged in a randomized complete block, with four replicates per treatment, organized into four blocks. Each individual mulch bed was one replicate, or "plot". Each individual plot was one, 0.9-by-8-m mulch bed, with one row of beans. Each plot contained 20 bean clusters, spaced 36 cm apart. This spacing equals one plant per 18 cm, which is slightly wider than most conventional recommendations. Wider spacing was used to achieve stand uniformity and sampling accuracy. Blocks were separated by no less than 100 m, in isolated locations of a diverse vegetable farm. Blocks were not adjacent to other snap beans plantings.

### 2015 (Early) Experiment

Beans were planted on 18 May 2015. Plots were arranged in a generalized, randomized complete block design, with nine replicate plots for each treatment, organized into three blocks. Each individual plot consisted of two, adjacent 0.9-by-3-m mulch beds, each with one row of beans per bed. Plots contained 10 bean clusters each, five per mulch bed. Blocks were separated by 10 m of fallow soil.

### 2015 (Late) Experiment

Beans were planted on 29 July 2015, and spatially separated by 350 m from the 2015 (early) location. Plots were arranged in a

generalized, randomized complete block design, with eight replicate plots for each treatment, organized into two blocks. Each individual plot consisted of four, adjacent 0.9-by 3-m mulch beds, each with one row of beans per bed. Plots contained 20 bean clusters each, five per mulch bed. Blocks were separated by 10 m of fallow soil.

### Insect Sampling

Insect populations were sampled once per week, and samples were taken in every plot. In each plot, 10 plant clusters were arbitrarily selected and visually inspected. Sampling was conducted on five dates for each experiment, starting on 9 July 2014, 11 June 2015, and 18 August 2015. Mexican bean beetles were counted as eggs, early larvae (first and second instars), late larvae (third and fourth instars), pupae, and adults. All predatory arthropods observed were documented.

### Plant Injury

#### Foliar Feeding

Mexican bean beetle feeding injury was evaluated in the 2015 experiments only, on 22 June (flowering stage) and 6 July (pod stage) for the early experiment, and 3 September (flowering stage) and 22 September (pod stage) for the late experiment. For each assessment, 10 plant clusters per plot were individually ranked on a scale of 0 to 5, indicating the level of feeding injury by Mexican bean beetle (Table 1).

#### Pod Feeding

One-hundred mature pods were arbitrarily selected from each plot on 17 July 2015 for the early experiment, and 23 September 2015 for the late experiment. Each pod was visually inspected for Mexican bean beetle feeding scars. A pod with a total combined area of scarred tissue  $\geq 1$  cm<sup>2</sup> was recorded as “damaged.” A pod with  $< 1$  cm<sup>2</sup> of scarred tissue was documented as “undamaged.”

#### Yield

All bean pods from every plot were hand-picked at pod maturity: 15 August 2014, 15 July 2015, and 23 September 2015. Pods were weighed the same day using an Adventurer Pro electronic scale (Ohaus Corp, Parsippany, NJ).

### Reflected Light Intensity (RLI), Temperature, and Humidity

RLI ( $\mu\text{mol}/\text{m}^2\text{s}$ ), temperature ( $^{\circ}\text{C}$ ), and relative humidity (%) were monitored from 2 June through 23 September 2015. Pyranometers

**Table 1.** Scale for rating Mexican bean beetle feeding injury on snap bean foliage

Ordinal rank	Definition of injury
0	No feeding injury
1	Less than five leaves exhibit injury; no leaf with more than 10% injury
2	Most leaves exhibit injury; no leaf with above 50% injury
3	Most leaves exhibit injury; 10 or less leaves with above 50% injury
4	Most leaves exhibit injury; more than 10 leaves with above 50% injury; some green remains
5	All remaining plant tissue (if any) is brown, and plant is likely dead

(QSO-S PAR sensor, Decagon Devices, Pullman, WA), which measure intensity of short wave-length light (400–700 nm), and temperature + humidity sensors (VP-4 Humidity Temperature Sensor, Decagon Devices, Pullman, WA) were mounted to metal poles, back to back, and staked between two plants. There were four poles with sensors in total: one for each treatment. Pyranometers were mounted 10 cm above the plastic or bare soil, facing the ground; temperature + humidity sensors were mounted 15 cm above the surface, also facing the ground. Pyranometers were calibrated weekly. A white, LED light was placed flat on the surface beneath each sensor at night, and mounts were microadjusted until all pyranometers produced readings within five intensity units of each other. To avoid bias and create replicates, sensors were relocated to a new plot and treatments weekly. Sensors were relocated 11 times, creating 12 replicates per treatment. Each pyranometer and temp/humidity sensor was connected to a data logger (Em50G Data Logger, Decagon Devices, Pullman, WA). Data loggers recorded conditions every 10 min and remained on at all times, except when units were being remounted.

### Data Analysis

All statistical tests were performed in JMP Pro 11 (SAS Institute Inc. 2007). Insect count data were analyzed by individual sample dates. Most insect count data did not fit normal distributions, either as raw data or after various transformations; therefore, nonparametric tests were used for analysis of insect densities. A Wilcoxon Rank Sum Test was used to detect significance within the model, followed by Wilcoxon Each Pair Test for multiple comparisons among treatments ( $\alpha = 0.05$ ). Yield, foliar injury, pod damage, RLI, humidity, and temperature all exhibited normal distributions, so the following parametric methods were used for analysis. Analysis of variance (ANOVA) was used to detect overall treatment effect within the model, followed by an Each Pair, Student's t-Test for multiple comparisons among treatments ( $\alpha = 0.05$ ). In 2014, insect counts and yield were dependent variables, analyzed separately. Treatment and block were independent variables, analyzed as fixed effects in both models. In 2015, foliar injury levels and % of pods damaged were additional dependent variables, analyzed independently as fixed effects. Also in 2015, the experimental design included within-block replication; so the treatment–block interaction was included in each model as a fixed effect. Per plot values for each dependent variable were calculated, and used as replicates in statistical models for all experiments.

## Results and Discussion

### RLI, Temperature, and Humidity

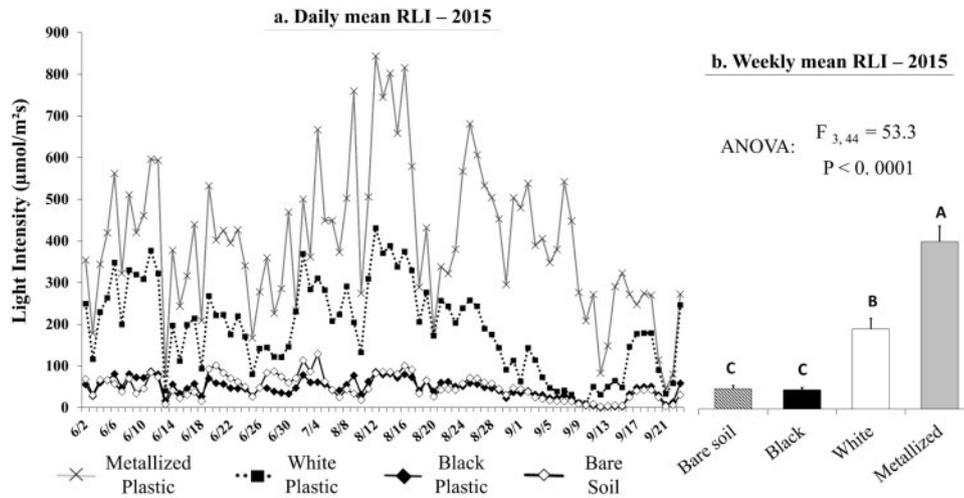
Temperature and humidity remained starkly similar among all treatments in 2015; however, clear and consistent trends were observed for RLI (Fig. 1a). Weekly average RLI on metallized plastic was significantly higher than all other treatments (Fig. 1b). White plastic RLI was significantly higher than black plastic and bare soil. Black plastic and bare soil RLIs were not different from each other.

In summary, temperature and humidity at canopy level were not affected by treatments. Metallized plastic was the most reflective treatment in terms of short wavelength light, followed by white plastic. Black plastic was not any more or less reflective than bare soil.

### Insects

#### Mexican Bean Beetle

Treatment effects for Mexican bean beetle life stages and instars closely coincided with the observed differences in RLI. In all three



**Fig. 1.** Mean reflected light intensities (RLI) on metallized mulch, white mulch, black mulch, and bare soil from readings taken every 10 min, starting at the first positive reading (sunrise) to the last positive reading (sunset); (a) daily means; (b) seven-day mean ( $\pm$  SEM) from 12 replicates per treatment. Values not sharing the same letter are different according to Student's *t* test ( $P < 0.05$ ).

seasons, metallized plastic plots harbored lower densities of Mexican bean beetle at all, or most, life stages compared to all other treatments. White plastic plots had the second lowest densities of Mexican bean beetle, while black plastic and bare soil plots experienced the highest beetle densities. Black plastic harbored more larvae, and bare soil harbored more adults and eggs.

Mexican bean beetle adults and eggs were found on 15 sample dates, over three seasons. Significantly fewer adults were found in metallized plastic plots than bare soil plots on seven dates, black plastic plots on six dates, and white plastic plots on six dates (Fig. 2a). Significantly fewer eggs were found in metallized plastic plots than bare soil plots on eight sample dates, black plastic plots on four dates, and white plastic plots on two dates (Fig. 2b). Mexican bean beetle early instars were found on 10 sample dates, and significantly fewer were found in metallized plastic plots than bare soil on two dates, black plastic plots on three dates, and white plastic plots on zero dates (Fig. 2c). Late instar larvae were found on five sample dates, and significantly fewer were found in metallized plastic plots than bare soil plots on two dates, black plastic plots on three dates, and white plastic plots on one date (Fig. 2d). Pupae were found on two sample dates, and significantly fewer were found in metallized plots than bare soil plots on one date. Late instar larvae or pupae were not found in the 2015 (late) experiment, likely due to cooler evening temperatures that limited development (Sweetman 1932, Mellors and Bassow 1983). Metallized plastic plots never harbored significantly higher number of Mexican bean beetles than any other treatment, for any life stage.

Overall, metallized plastic considerably reduced densities of Mexican bean beetle at all life stages. White plastic exhibited a similar, but less pronounced effect. Light intensity, temperature, and humidity are the most important environmental factors that limit Mexican bean beetle's potential to damage crops (Howard and English 1924, Miller 1930, Auclair 1960, Kitayama et al. 1979, Wilson et al. 1982). Because Mexican bean beetle densities decreased relative to increasing RLI, while temperature and humidity were unaffected, it is likely that RLI was responsible for the reduced beetle density.

#### Predatory Arthropods

The predominant predatory arthropods observed in this experiment were spiders (Araneae), lady beetles, damsel bugs (Hemiptera:

Nabidae), minute pirate bugs (Hemiptera: Anthocoridae), and spined soldier bug, *Podisus maculiventris* (Say) (Hemiptera: Pentatomidae). Only spiders and spined soldier bugs were significantly affected by treatments (Table 2). In 2014, more spiders were found in metallized plastic than black plastic and bare soil; white plastic had more spiders than bare soil. In 2015 (early), there was, again, a significant effect of treatment on spiders, with black plastic and white plastic having higher densities than bare soil. Also in 2015 (early), more spined soldier bugs were found in black plastic than bare soil and white plastic.

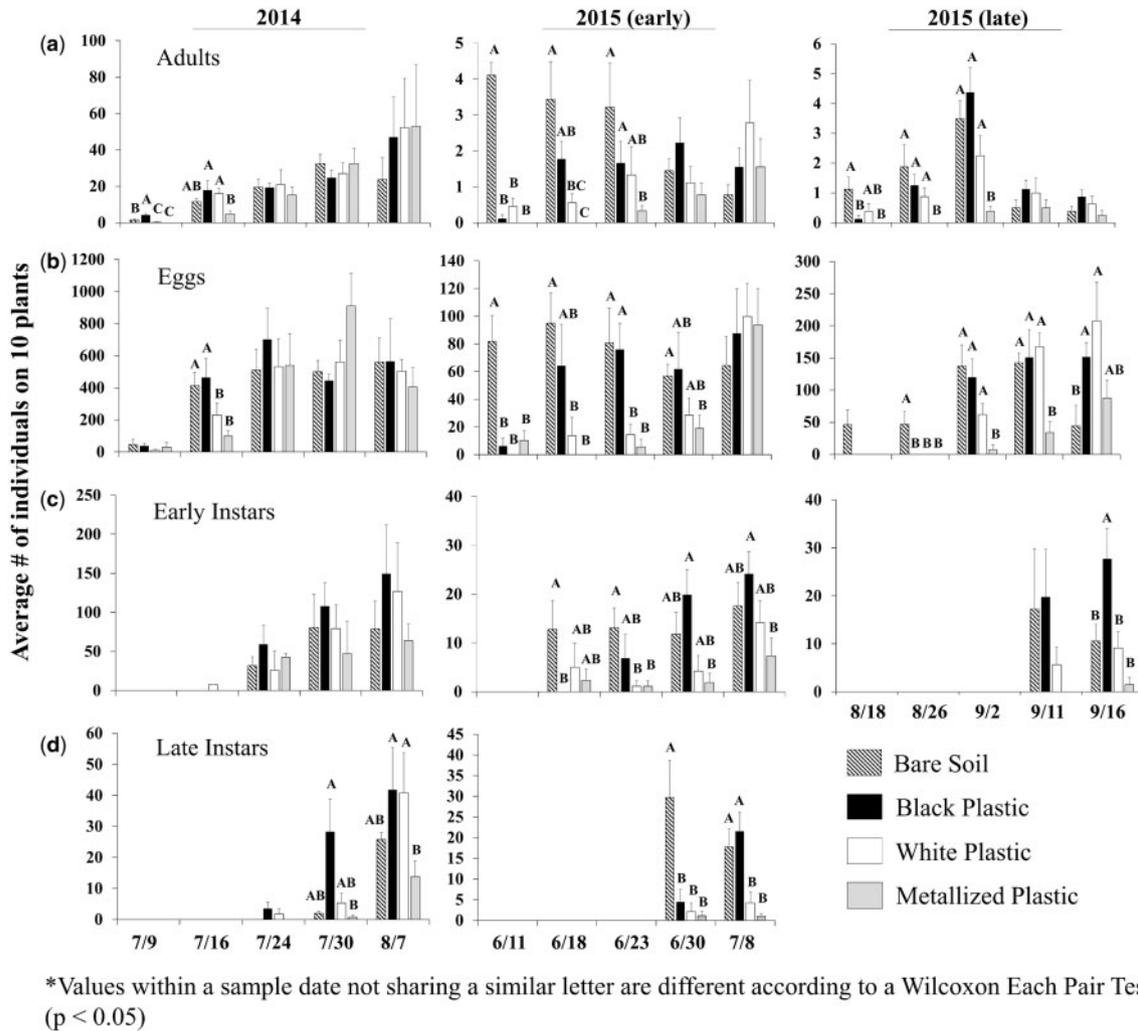
Overall, the treatment effects witnessed in these experiments were marginal, and cannot be explained without a high degree of speculation. It is more worthwhile to emphasize that there was no evidence to suggest that either metallized or white plastic will reduce predator numbers compared to the conventional strategy of planting on bare soil. Simmons et al. (2010) also found reflective mulches to have no adverse effects on natural enemies of whiteflies.

#### Plant Injury

After the 2014 experiment, it became apparent that plots with heavily infested and injured plants early in the experiments had lower carrying capacities for beetles later in the experiments, compared to less infested plots. Therefore, density data becomes less accurate, or useful, toward the end of experiments. For example, a heavily fed upon plot may have the same, or fewer late instar Mexican bean beetles than a slightly fed upon plot; but the data suggest that there is no difference between the two. Wells et al. (1984) observed a similar phenomenon, when healthier and less injured beans on reflective mulch harbored more potato leafhoppers as the plants neared maturity. For the 2015 experiments, assessments of feeding injury by Mexican bean beetle were added to more thoroughly document pest pressure.

#### Foliar Feeding

In the 2015 (early) experiment, there was a significant effect of treatment on Mexican bean beetle foliar injury at both flowering and pod stages. Plants in bare soil plots had the highest level of foliar injury, followed by black plastic, white plastic, and metallized plastic, respectively (22 June 2015:  $F = 29.9$ ;  $df = 3, 32$ ;  $P < 0.0001$ . 6 July 2015:  $F = 20.7$ ;  $df = 3, 32$ ;  $P < 0.0001$ . Fig. 3a).



**Fig. 2.** Mexican bean beetle (a) adults (first column), (b) eggs (second column), (c) early instars (third column), and (d) late instars (bottom column), observed in snap beans grown on metallized mulch, white mulch, black mulch, and bare soil. Values shown are the mean densities ( $\pm$ SEM) of individuals on 10 plant clusters per plot, from four replicates per treatment in 2014 (left column), nine replicates in 2015 (early) (middle column), and eight replicates in 2015 (late) (right column).

**Table 2.** Mean cumulative densities ( $\pm$ SEM) of predatory arthropods from 2014 and 2015 (early) observed on 10 snap bean plant clusters per plot over five sample dates, grown on different plastic mulch treatments and bare soil

	Spiders	Lady beetles <sup>a</sup>	Damsel bugs	Minute pirate bugs	Spined soldier bugs
<b>2014</b>					
Bare soil	2.3 $\pm$ 0.6c	5.0 $\pm$ 2.3	1.3 $\pm$ 0.8	0.3 $\pm$ 0.0	0.0 $\pm$ 0.0
Black plastic	2.8 $\pm$ 0.5bc	5.0 $\pm$ 0.4	2.0 $\pm$ 0.8	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
White plastic	7.5 $\pm$ 2.9ab	8.8 $\pm$ 2.8	0.5 $\pm$ 0.3	0.8 $\pm$ 0.3	0.5 $\pm$ 0.0
Metallized plastic	7.3 $\pm$ 1.7a	5.3 $\pm$ 1.7	1.3 $\pm$ 0.8	0.5 $\pm$ 0.0	0.0 $\pm$ 0.0
Statistics	$\chi^2_{3, 12} = 10.5, P = 0.0148$	ns	ns	ns	ns
<b>2015 (early)</b>					
Bare soil	2.0 $\pm$ 0.4b	1.1 $\pm$ 0.5	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	0.1 $\pm$ 0.1b
Black plastic	4.0 $\pm$ 0.7a	1.4 $\pm$ 0.4	0.3 $\pm$ 0.2	0.1 $\pm$ 0.1	0.8 $\pm$ 0.3a
White plastic	4.9 $\pm$ 0.9a	0.6 $\pm$ 0.2	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0b
Metallized plastic	2.6 $\pm$ 0.5ab	0.7 $\pm$ 0.3	0.3 $\pm$ 0.2	0.0 $\pm$ 0.0	0.2 $\pm$ 0.1ab
Statistics	$\chi^2_{3, 32} = 8.8, P = 0.0315$	ns	ns	ns	$\chi^2_{3, 32} = 8.8, P = 0.0320$

Values within a column not sharing a similar letter are different according to a Wilcoxon each pair test ( $P < 0.05$ ).

Predator numbers from the 2015 (late) experiment were too low for analysis.

<sup>a</sup>Ninety percent of lady beetles were *Coleomegilla maculata* (De Geer). Other species included *Hippodamia convergens* Guérin-Méneville, *Coccinella septempunctata* L., and *Harmonia axyridis* (Pallas).

Similar treatment effects were observed in the late experiment. At flowering stage, bare soil had the most injury, followed by black plastic, white plastic, and metallized plastic, respectively ( $F=34.8$ ;  $df=3, 28$ ;  $P<0.0001$ , Fig. 3b). At pod stage, plants on metallized plastic had significantly less foliar injury than all other treatments, and injury was not different among bare soil, black plastic, and white plastic ( $F=9.3$ ;  $df=3, 28$ ;  $P=0.0003$ , Fig. 3b).

The correlation between foliar feeding injury by Mexican bean beetle and RLI was very similar to the Mexican bean beetle density results. Feeding injury decreased with increasing RLI, suggesting that increasing RLI, via reflective plastic mulch, reduced pest pressure from Mexican bean beetle. The only deviation was that black plastic experienced reduced injury compared to bare soil, though RLI between black plastic and bare soil were similar. This suggests that plastic, regardless of color, has some ability to reduce injury from Mexican bean beetle.

Our experiments demonstrated that Mexican bean beetle injury was negatively correlated to increasing light intensity from plastic mulches. Differences in beetle densities are likely responsible for decreasing injury levels in white and metallized plots, respectively. It is also possible that individual beetles feed less under higher stress from increased light intensity. Miller (1930) reported that when Mexican bean beetles were exposed to direct light, they became restless, stopped feeding, and initiated relocation behavior. This may mean that beetles spend more time moving than feeding, when

exposed to direct light. More research is needed to determine if reflective mulches may limit the feeding potential of individual beetles, in addition to suppressing their population.

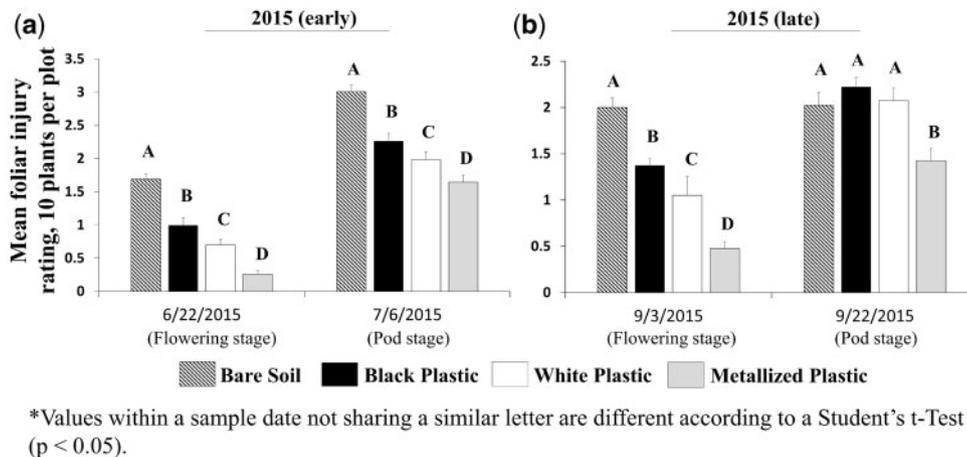
### Pod Feeding

There was a significant effect of treatment on damaged pods in both 2015 experiments. Most notably, fewer pods were damaged by Mexican bean beetle in metallized plastic plots than bare soil plots in both 2015 experiments (Table 3). White plastic reduced pod damage compared to bare soil in the 2015 (early) experiment, and black plastic reduced pod damage compared to bare soil in the 2015 (late) experiment.

These results further suggest that metallized plastic mulch reduces Mexican bean beetle feeding injury on snap beans, and also show that white and black plastic exhibit a lesser potential at the same goal. Again, it is unclear whether the reductions in feeding damage were the result of lower beetle densities, reduced feeding on an individual level, or both.

### Yield

There was a significant effect of treatment on yield in 2014 and 2015 (early) (Table 3). In 2014, plants on metallized plastic produced significantly more pods by weight (yield) than all other treatments. The average yield from metallized plastic plots was more than two times greater than white plastic and black plastic (individually), and five times greater than bare soil. White plastic and



**Fig. 3.** Mexican bean beetle foliar feeding injury levels to snap bean plants grown on metallized mulch, white mulch, black mulch, or bare soil in (a) 2015 (early) and (b) 2015 (late). Individual plants were rated on a scale of 0–5 (Table 2). Values shown are the mean ratings ( $\pm$ SEM) of 10 plant clusters per plot, from nine replicates per treatment in 2015 (early) and eight replicates in 2015 (late).

**Table 3.** Mean snap bean yield ( $\pm$  SEM) from 2014, 2015 (early), and 2015 (late), and mean number of pods damaged by Mexican bean beetle ( $\pm$  SEM) from 2015 (early) and 2015 (late), harvested from 10 plant clusters in four replicates per treatment in 2014, nine replicates in 2015 (early), and eight replicates in 2015 (late)

Treatment	2014	2015 (early)		2015 (late)	
	Yield (g) per 10 plants	Yield (g) per 10 plants	% Damaged pods <sup>a</sup>	Yield (g) per 10 plants	% Damaged pods <sup>a</sup>
Bare soil	527.5 $\pm$ 379.5c	1023.6 $\pm$ 168.1b	67.0 $\pm$ 4.1a	60.6 $\pm$ 7.9	33.8 $\pm$ 3.3a
Black plastic	1121.7 $\pm$ 714.7b	1121.0 $\pm$ 213.1b	51.1 $\pm$ 3.2b	74.9 $\pm$ 6.9	27.1 $\pm$ 2.4ab
White plastic	1263.1 $\pm$ 683.9b	1372.9 $\pm$ 150.7b	41.1 $\pm$ 5.0bc	104.6 $\pm$ 6.8	29.8 $\pm$ 2.8a
Metallized plastic	2699.4 $\pm$ 1110.7a	2115.1 $\pm$ 302.1a	39.0 $\pm$ 4.2c	82.1 $\pm$ 8.2	20.0 $\pm$ 3.6b
Statistics	$F_{3, 12} = 12.3, P = 0.0015$	$F_{3, 32} = 5.0, P = 0.0077$	$F_{3, 32} = 10.5, P = 0.0001$	n/a <sup>b</sup>	$F_{3, 28} = 5.1, P = 0.0069$

Values within a column not sharing a similar letter are different according to Student's t-test ( $P < 0.05$ ).

<sup>a</sup>Number of damaged pods out of 100 per plot.

<sup>b</sup>Yield data from 2015 (late) were not analyzed due to extremely low production.

black plastic were similar, and also produced significantly higher yields than bare soil. In the 2015 (early) experiment, metallized plastic plots had significantly higher yields than all other treatments, with double the yield of bare soil plots. Yields were not different among white plastic, black plastic, or bare soil. In the 2015 (late) experiment, yields for all treatments were much lower than in the previous two experiments (94% lower than the previous seasons) due lower than normal temperatures in August and September, and consequently, these data were not analyzed.

Our experiments alone cannot define the exact mechanism(s) linked to the observed differences in snap bean yields. Reflective mulches may have affected yields indirectly, by suppressing Mexican bean beetle, or by directly influencing plant health and vigor (or a combination of both). Previous research corroborates both mechanisms. Mexican bean beetle feeding injury has been shown to reduce snap bean yield after ~20% defoliation (Capinera et al. 1987, Fan et al. 1993). In our study, almost all plants in bare soil plots greatly surpassed 20% defoliation, as did many plants in black plastic plots, making it very likely that feeding injury was at least partially responsible for yield differences. In addition to limiting insect pressure, higher light intensity environments have been shown to enhance snap bean vigor by increasing the dry weight of roots and shoots, leaf sugar concentrations, and density of stomata in leaves (Knecht and O'Leary 1972, Marschner and Cakmak 1989). Throughout our experiments, light intensity was significantly higher in metallized plots than all other treatments, especially bare soil and black plastic. Furthermore, reflective mulches keep soil temperatures lower than black plastic and bare soil (Ham et al. 1993, Lament 1993), which can prevent certain types of injury to snap beans, such as chlorosis, stunted growth, underdeveloped nodules, and reduced ability to fix nitrogen (Piha and Munns 1987). In a similar study to ours, Wells et al. (1984) applied insecticides in combination with reflective mulch treatments, and found that reflective mulch increased snap bean yields, regardless of insect pressure. Considering these previous studies in regard to our results, it is likely that the yield differences seen in our experiments were the result of combined direct (plant response) and indirect (pest response) mechanisms related to mulch treatments.

### Implications

Our experiments demonstrated that growing snap beans on the highly reflective plastic mulch, "metallized" (Sunup Reflective Films, Oceanside, CA), reduced the severity of Mexican bean beetle and increased yields, relative to treatments that were decreasingly reflective. In determining the implications of these findings, it is important to consider that there are various types of reflective mulches, with different constructions and levels of reflectivity. Although our findings suggest that other highly reflective plastic mulches will produce control of Mexican bean beetle and increase yields, this claim cannot be substantiated without further testing of other reflective mulch types. Future studies should also consider the planting density of snap bean on reflective mulch, so that this method can be optimized for commercial scale production. In our experiments, plants were widely spaced in clusters, to facilitate accurate data collection; however, commercial recommendations suggest closer spacing of snap beans. Lastly, this method should be evaluated in more locations. Alternate locations will have different climates and insect populations, which may alter the effects of reflective plastic mulches.

Assuming that our results can be applied to other reflective mulch types, growing strategies, and locations, reflective mulch may serve as a practical IPM tool for snap beans producers. An important

component of IPM involves using methods that prevent or reduce potential for pest population growth (especially those that do not require chemical applications). Although foliar and pod injury was not entirely avoided with metallized mulch in our experiments, a substantial overall increase in clean marketable pods was achieved without the use of any other control tactic. Another element of a strong IPM strategy is multi-functionality. Planting snap beans on metallized mulch has been shown to control other snap bean pests, such as potato leaf hopper and thrips, while also providing an effective barrier against weeds.

A likely challenge in the adoption of this method by growers will be the up-front cost of metallized plastic mulch. The current price of metallized plastic ranges from 10 to 35% more than black plastic. This monetary cost may be offset directly by the reduction in insecticides, herbicides, and time spent applying pesticides, as well as increases in overall yield, fewer insect-damaged pods, and cleaner pods (due to the barrier between pods and soil). To increase profits for each mulch application, growers may consider employing a double crop strategy, in which a second round of beans or an alternate crop is directly planted into the plastic after the first crop is harvested. For example, after the 2015 (early) experiment was harvested, bean plants were pulled and 20 lettuce plants were transplanted directly into each treatment bed (40 total lettuce plants per plot). Not only did lettuce grow adequately in the reused mulch, we witnessed 60% higher yields in metallized plots than bare soil plots, and 25% higher yields than in black plastic plots (Louis Nottingham, unpublished). Numerous other crops have shown similar benefits from reflective mulches (specific details are discussed in the Introduction section), and may be successful in a double-crop planting strategy.

Due to the small scale of these experiments, the findings of this study should be considered at the proof-of-concept level until further research is completed. Future studies should incorporate planting schemes that more closely represent a commercial growing scenario. Growing snap beans on metallized should be initiated on a trial basis, with careful monitoring of pests, the environment, and economic factors.

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