

ABSTRACT

Title of Thesis:

DEVELOPING A PERENNIAL LIVING
MULCH SYSTEM FOR MANAGING PESTS
AND AUGMENTING NATURAL
BIOCONTROL IN MARYLAND
CANTALOUPE SYSTEMS

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This study investigated how alsike clover (*Trifolium hybridum*) and Virginia wildrye (*Elymus virginicus*), when interplanted as a living mulch with cantaloupe, (*Cucumis melo* var. *cantalupensis*) would impact herbivorous and beneficial arthropod numbers. An additional objective was to determine how these living mulches would impact fruit yield and quality. It was hypothesized that there would be a reduction of cantaloupe pest herbivores and increase in natural enemy abundances in the interplanting compared to monoculture cantaloupe system. Some arthropods conformed to these expectations. However, most had a neutral or inconsistent response to the living mulches. Striped cucumber beetles (*Acalymma vittatum*), a major pest, were unaffected by the living mulches on most sampling dates. During several periods in both study years, leaf piercing herbivores including aphids were found in greater numbers on cantaloupe interplanted with clover than wildrye and/or monoculture. Spiders were found in greater abundance in cantaloupe interplanted with clover than wildrye or monoculture plantings during several sampling periods. Other natural enemy guilds such as parasitic wasps and piercing predators were inconsistently influenced by living mulch types. Yield was highest in the monoculture plots and living mulch was correlated with changes in fruit texture and color.

DEVELOPING A PERRENIAL LIVING MULCH SYSTEM FOR MANAGING PESTS AND
AUGMENTING NATURAL BIOCONTROL IN MARYLAND CANTALOUPE SYSTEMS

By

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Developing a Perennial Living Mulch System for Managing Pests and Augmenting Biocontrol in Maryland Cantaloupe Systems

Introduction

Cucurbit growers in the mid-Atlantic region face an assortment of economically important pests. Striped cucumber beetle (*Acalymma vittatum*), spotted cucumber beetle (*Diabrotica undecimpunctata*), squash vine borer (*Melittia cucurbitae*), melon aphid (*Aphis gossypii*), green peach aphid (*Myzus persicae*), and other herbivores can impact cucurbit production. Direct feeding damage can be harmful; however, insect vectored disease transmission is the chief concern of many cucurbit growers. Cantaloupe (*Cucumis melo* var. *cantalupensis*) is considered the second most vulnerable cucurbit crop to insect pests due to its susceptibility to diseases (ATTRA, 2008). Aphids are known to vector several viral diseases that affect cantaloupe, such as watermelon mosaic virus (WMV) and cucumber mosaic virus (CMV) (Gallitelli, 2000). Striped cucumber beetles are considered the most significant cucurbit pests in the mid-Atlantic mostly due to their ability to transmit bacterial wilt (Metcalf & Metcalf, 1992) which when established in a field can quickly spread and cause total yield loss (Mitchell & Hanks, 2009).

To combat pest issues such as insect vectored disease transmission, growers often rely on frequent applications of chemical pesticides which can have adverse effects on the environment, agricultural profits, and human health (Geiger et al., 2010; Relyea, 2016; Weisenburger, 1993). A common practice for pest mitigation in cantaloupe is the systemic application of neonicotinoids to protect young seedlings which are the most vulnerable growth stage (CMCC, 2003). Cantaloupe's vulnerability to insect damage and insect vectored plant diseases also causes growers to administer

frequent prophylactic sprays of pyrethroids during later plant stages. Some extension programs suggest foliar applications of pyrethroids when a threshold of one striped cucumber beetle per plant is observed (Brust & Foster, 1999). In general, the heavy reliance on chemicals for pest control has received wide public scrutiny because of its association with declining pollinator populations (Van der Sluijs et al., 2013). Frequent pesticide applications have also contributed to the development of insecticide resistance among melon aphids (Wang et al. 2002), and a decline in pollinators and natural enemies which make conditions conducive to secondary pest outbreaks and additional sprays (Geiger et al., 2010). Further, the value of insecticide sprays for controlling cucumber beetles has been scrutinized as many adults reside at the plant's base and their immature stage inhabits the soil where they are shielded from sprays (Brust, 2017; Shelton et al., 1993). This suggests the need for additional management options.

An alternative management tactic is to enhance the level of plant diversification within a cropping system. This strategy is often deployed to attract beneficial arthropods and consequently improve ecosystem services such as pollination and biocontrol (Bowers et al, 2020; MacLeod et al. 2004). Plant diversification can exist in many forms and may include adding strips of grass or flowering plants along the borders or within crop fields or increasing the numbers of different crops within an area (Picket, 2014; MacLeod et al., 2004). Another practice is to interplant a living cover crop within the cash crop. Cover crops that are interplanted with a cash crop and live the entire duration of the cash crop's lifecycle are known as living mulches (Schmidt, 2007). Living mulches interplanted within cash crops have been shown to reduce pest colonization and associated yield losses in some agricultural systems, including cucurbit crops. For example, recent studies have shown that interplanting zucchini and cucumber with a living mulch resulted in reduced

numbers of insect herbivores and greater abundance of natural enemies (Hinds & Hooks, 2013; Kahl et al. 2019).

Growing crops with neighboring heterospecific plants to decrease herbivory may be used to harness what is known as associational resistance. This tactic may require fewer chemical inputs within the cropping system and can potentially be more cost effective than using pesticides. How associational resistance contributes to a reduction in pests can tentatively be explained by two non-exclusive hypotheses. The resource concentration hypothesis predicts that specialist insect herbivores will be more abundant in large continuous patches of their preferred host plants and that increased plant diversity in a cropping system makes it more difficult for these herbivores to detect their host plants (Root, 1973). The natural enemy hypothesis suggests that greater plant species richness in an agricultural settings promotes colonization by natural enemies (Root, 1973). Increased abundance of natural enemies may be attributed to enhanced availability of alternate food items and more variable niches in complex habitat. More complex habitat may also allow certain predators to forage more effectively. For example, the wolf spider (family: Lycosidae) can more effectively hunt prey such as cucumber beetles in more complex habitats where they can lay in ambush or conceal themselves from prey (Snyder & Wise, 2000). Visual and chemical cues given off by the presence of wolf spiders have been shown to reduce striped cucumber beetle feeding and residence time as well (Williams & Wise, 2003). Additionally, it has been proposed by Root (1973) that greater numbers of alternate prey and increased structural diversity can reduce competition between predators for similar food items.

An effective living-mulch system should preserve or enhance a grower's economic returns. Competition with other plants may reduce melon yield and quality, especially if it occurs during the first month after melon germination (Nerson, 1989). Though most past research with

living mulches has focused on total yield, produce quality is important to consumer acceptance. Properties used to evaluate fruit quality often include fruit size and weight, as well as color, taste, aroma and texture, which represents structural and biochemical changes associated with ripening (Shackel et al., 1991; Brummel and Harpster, 2001; Giovannoni, 2004; Saladie et al, 2007; Bouzayen et al. 2010). Fruits accumulate non-photosynthetic pigments and lose chlorophyll as they ripen, which in cantaloupe manifests as yellowing of the fruit's skin. Additionally, ripening fruit will accumulate sugar, produce aromatic volatiles, and experience tissue softening (Osorio and Fernie, 2013; Seymour et al., 2013). These characteristics directly impact the palatability of fruits to consumers and indicate that they are ripe and of high quality (Obando-Ulloa et al., 2009, Burger et al., 2014). A consumer survey carried out by Lester (2006) across a variety of melon cultivars showed that melon acceptability to consumers is highly correlated with flavor, sweetness, and texture. Additionally, consumers are more sensitive to changes in texture than flavor (Beaulieu et al., 2004; Shewfelt, 1999) and often prefer softer fruits to firmer ones. However, tissue softness can come at a cost with respect to fruit's shelf life and storability (Usenik et al., 2008; Farcuh et al., 2020a). Farcuh (2020b) found that instrument-based assessments of texture correlated well with sensory based evaluations and thus can be useful to evaluate fruit quality.

The goal of this study was to determine if interplanting a living mulch with cantaloupe would result in fewer cantaloupe pest herbivores and greater abundance of beneficial arthropods, as well as determine the impact of interplanted living mulches on cantaloupe quantity and quality. An additional goal was to compare two plant species that are structurally dissimilar. Thus, Virginia wildrye (*Elymus virginicus*) and alsike clover (*Trifolium hybridum*) were chosen as the test living mulches. Past studies have shown that legumes such as crimson clover (*Trifolium incarnatum*) and red clover (*Trifolium patense*) and grasses such as cereal rye (*Secale cereal L.*) can be used to

enhance natural enemies and/or reduce pest colonization (Bowers, et al. 2020; Kahl et al. 2019), and that perennial grasses can serve as refugia for overwintering natural enemies (MacLeod et al. 2004). Alsike clover is a cold-tolerant native perennial species, and it was hypothesized that it would provide similar benefits to red clover with respect to reducing pest numbers and enhancing natural enemy abundances. In contrast, Virginia wildrye is a perennial bunch grass that may provide similar benefits to cereal rye and other grasses (*Agrostis stolonifera*, *Dactylis glomerata*, *Holcus lanatus* and *Lolium perenne*) as shown in MacLeod et al., (2004) and Bowers et al., (2020). Additional goals included determining treatment impact on fruit yield and quality. Thus, fruit size, weight, soluble solid (sugar) content, rind and flesh color, and firmness were evaluated.

Materials and Methods

Experimental layout and design

Field experiments were conducted during the summers of 2020 and 2021 at the University of Maryland's Central Maryland Research and Education Center in Upper Marlboro, MD. The experiment consisted of three treatments: 1) cantaloupe interplanted into alsike clover (clover) or 2) Virginia wildrye (wildrye), and 3) cantaloupe monoculture/bare-ground (monoculture). The experiment was replicated four times and arranged in a randomized complete block design. Each plot measured 12.1 m by 12.1 m and was separated by 7.6 m alleys consisting of naturally occurring mowed vegetation. Each plot contained eight rows of cantaloupe with an intra- and interrow spacing of 91 cm and 1 m, respectively. Each row consisted of 13 cantaloupe plants. The variety of cantaloupe used was sugar cube (Johnny's Selected Seed, Winslow, ME, USA).

Alsike clover and Virginia wildrye were seeded in their respective treatment plots with a no-till drill in September of 2019 and 2020 prior to the subsequent field season. In 2019, the

alsike clover was seeded at a rate of ~ 7 kg/ha and the Virginia wildrye at ~ 17 kg/ha. In 2020, the seeding rate for each was increased to ~ 9 kg/ha for alsike clover and ~ 25 kg/ha for Virginia wildrye to achieve a fuller stand for each living mulch. Monoculture plots remained fallow over the winter. In 2020, entire monoculture plots were rotary tilled approximately a week prior to transplanting the cantaloupe. Living mulch treatment plots were strip tilled at a width of 38 cm within the intra-rows using a rear tine garden tiller on June 25 and cover crops remained in the inter-row areas as a living mulch. The living mulches were mowed once before transplanting with a push mower to reduce early seasons competition with the young cantaloupe transplants. In 2021, living mulch treatment plots were strip tilled on June 3rd, $\sim$ four weeks before transplanting the cantaloupe on June 29th. This was to facilitate the “stale seedbed technique” in which weeds were allowed to germinate in the strips and subsequently sprayed with Glyphosate before transplanting the cantaloupe. Cantaloupe seedlings were grown in a greenhouse for roughly 2.5 weeks before they were hand-transplanted. Transplant holes were made with a handheld soil auger and after being placed in the soil, 170 ml of 1.3% miracle grow solution (18N-24P-12K) were poured into each hole. Any transplants that didn’t successfully establish over the next two weeks were replanted. Plots were drip irrigated to supplement periods of low rainfall.

Insect Data Collection

Arthropod sampling began roughly two weeks after the cantaloupe was transplanted (July 15 in 2020 and 2021). Visual counts, yellow sticky cards, and pitfall traps were used to monitor arthropod numbers. For visual counts of foliar arthropods, a square meter quadrat was placed randomly in each of the six interior cantaloupe rows of each plot, at a minimum of 1.5 m from the plot edge centered on a cantaloupe plant. All arthropods encountered on the foliage or visible

on the soil surface within the quadrat were identified to the lowest taxonomic level achievable and recorded. Visual counts were repeated every week until harvesting initiated (July 28, 2020 and July 18, 2021).

Yellow sticky cards (12.7 x 7.6 cm) were used mainly for detection of aerial active arthropods. Cards were deployed during three time periods each season to represent early, mid and late cantaloupe development stages (July 17, August 10 and August 27 in 2020; July 15, August 5 and August 25 in 2021). One card was placed in the intra- and interrow area every three weeks. Cards were placed at canopy height and attached to fiberglass poles with clothes pins. They were placed near the center of each plot and remained in the field seven days prior to collection. After collection, sticky cards were transferred into Ziploc bags and placed into a freezer. Card specimens were later identified to the lowest taxa possible using a stereomicroscope.

Pitfall traps were used mainly to monitor epigeal predators such as ground beetles (Carabidae), wolf spiders (Lycosidae) and rove beetles (Staphylinidae). Pitfall traps were deployed on a similar schedule as yellow sticky cards. Pitfall traps consisted of two nested 0.27 L plastic cups buried flush with the soil. A 30 x 30 cm black plastic cover held to the ground with 5 cm screws was placed above each trap to keep out wildlife. Traps consisted of propylene glycol as the trapping/killing agent. When trap contents were collected, specimens were transferred to a container with 70% ethanol and later identified under a stereomicroscope. Guild assignment for arthropods from trap captures was determined according to information obtained from Arnett and Thomas (2000), Marsh (1994), Marshall (2018), Marshall (2012), Ross et al. (2002), and Triplehorn et al. (2005).

Fruit Yield and Quality

Harvesting began on July 28 in 2020 and July 24 in 2021 with the appearance of ripe fruit. Ripe fruit were determined by vine slippage, or the separation of the vine from the fruit pedicle (CMCC, 2003). On each harvesting date ripe fruits more than 1.2 m from the edge of each plot were collected and weighed to calculate marketable yield. Only marketable fruit were used for yield data. On the initial harvest date, four marketable fruit from each plot were brought back to the University of Maryland campus for quality evaluation (16 fruits/treatment). The cantaloupe quality analysis involved measuring various indices of size, color, texture, and sugar content. The fruit's polar and equatorial diameters were measured to the nearest centimeter. Thereafter, the fruit poles were cut off and the remaining equatorial region formed a thick disk with exposed skin and flesh. Colorimeter readings were taken from the equatorial region using a Konica Minolta Colorimeter. Two exposed flesh and two skin readings were taken from opposite sides of the fruit. Readings from the colorimeter generated data for the chroma and hue angle of fruit using the CIELAB color space defined by the International Commission on Illumination. In the CIELAB color space hue angle (h) is derived from where a color intersects the space's red-green (a^*) and yellow-blue (b^*) axes. Hue angle is expressed in degrees where 0° ($+a^*$) is red, 90° ($+b^*$) is yellow, 180° ($-a^*$) is green, and 270° ($-b^*$) is blue. Chroma (C^*) refers to the saturation or brightness of a color, or the perceived difference between it and a neutral grey of the same lightness (L^* , the position on the black-white axis) (CIE, 2004).

Cubes of 2.5 cm thickness were cut at a standardized depth of ~ 1 cm beneath the cantaloupe rind and then pressed into juice for soluble solid (sugar) content, acid, or texture analysis. To attain juice samples free of pulp for the soluble solid, cubes were placed into a garlic press with a folded piece of cheese cloth acting as a filter to catch the pulp. A small amount of

the clear filtered juice was pipetted onto the sensor of a handheld electronic spectrometer to obtain the percent soluble solid content of the juice. To analyze texture, the remaining cubes were inserted into a Ta.XT Texture Analyzer. A puncture test using a 5-mm diameter stainless steel cylindrical TA212(5/16) probe traveling 6mm after contact with the rind side of each fruit sample provided data for fruit firmness, measured as the maximum value of the peak force of the output curve in N.

Statistical Analysis

Herbivore and natural enemy taxa were grouped by feeding guilds to compare abundance across treatments (chewing herbivores and predators, piercing herbivores and predators, spiders, detritivores, parasitoids, and pollinators). Certain taxa which are of significant importance to the cantaloupe system as potential economic pests or their natural enemies, such as striped cucumber beetles and aphids, and generalist predators such as ground beetles (Carabidae), rove beetles (Staphylinidae) and wolf spiders (Lycosidae) were analyzed separately as well as grouped into overall feeding guilds for the analysis. For visual counts, data for each row were converted into number per square meter and averaged across each plot for each date. Using the statistical software program “R” (R Development Core Team), a linear mixed effect model (“lmer”, lme4 package) was used to determine the significance of treatment and date as fixed effects as well as their interaction. Plot and replication were included in the model’s error term. When a significant date interaction was detected alongside a significant treatment effect, pairwise comparisons among treatments were carried out with a Tukey-Kramer test for each level of date (“emmeans”, car package). In the absence of a date interaction the test was instead carried out between treatments averaged across all dates.

Trap captures were also analyzed using a linear mixed effect model. Each collection date was analyzed separately to provide an assessment of arthropod abundances during the early, mid and late stages of cantaloupe's growth cycle. Trap positions within each plot were averaged, and when a treatment effect was detected a Tukey-Kramer test was carried out between treatments to determine significant effects.

To analyze cantaloupe yield, the cumulative weight of all fruit collected in each plot were averaged for each treatment. Measurements of melon quality (e.g., dimensions, color, soluble solids, and texture) were averaged for each plot. For yield and fruit quality data, effect of treatment was tested with a one-way ANOVA (`aov()`, base R) and when treatment was significant, a Tukey-Kramer test was conducted to make simultaneous pairwise comparisons between each treatment.

Results

Arthropod Abundance

Visual counts- In 2020 and 2021 there was no treatment differences in striped cucumber beetle numbers from foliar counts (Figure 1). Striped cucumber beetles remained low throughout the study and did not exceed one beetle per square meter, which was used as a proxy for beetles per plant. Comparably, aphid counts were similar among treatments and remained lower than one individual per square meter. For natural enemies, there was a significant treatment effect on spiders in 2020 ($\chi^2 = 6.92$, $df = 2$, $P = 0.031$) and 2021 ($\chi^2 = 26.13$, $df = 2$, $P < 0.0001$), and a significant date by treatment interaction ($\chi^2 = 46.9$, $df = 12$, $P < 0.0001$; 2020) and ($\chi^2 = 58.69$, $df = 10$, $P < 0.0001$; 2021). In 2020, at 34 ($P = 0.02$) and 56 ($P < 0.0001$) days after planting (DAP) more spiders were found in clover than wildrye. Also, at 34 DAP more were found in monoculture than wildrye ($P = 0.0007$). In 2021, more spiders were found in clover than

monoculture at 23, 30, 37 and 44 DAP ($P \leq 0.042$), with 59% higher captures in clover than monoculture across the entire 2021 season. Spider counts were also greater in clover than wildrye at 30, 37 and 44 DAP ($P \leq 0.0003$) and were 40% higher in clover than wildrye throughout the season. Counts were also higher in wildrye than monoculture at 30 DAP ($P = 0.019$) and the number captured was 18% higher in wildrye than monoculture over the season (Figure 2).

Yellow Sticky Cards- Similar to foliar counts, numbers of striped cucumber beetle detected on yellow sticky cards were similar among treatments and did not exceed the 15-beetle per card action threshold during any sampling period. However, unlike foliar counts, differences were detected among treatments in aphid numbers on sticky cards. In 2020, differences occurred during mid- (39 DAP, $\chi^2 = 11.17$, $df = 2$, $P = 0.004$) and late-season (56 DAP, $\chi^2 = 8.37$, $df = 2$, $P = 0.025$). During both periods, aphid counts were higher in clover than wildrye ($P \leq 0.047$) (Table 1). In 2021, a significant treatment effect was detected during all three stages (16 DAP: $P = 0.002$, 37 DAP: $P = 0.042$ and 57 DAP: $P = 0.018$). At 16 DAP, aphid numbers were higher in monoculture than wildrye ($P = 0.018$) and at 37 DAP numbers were marginally higher in clover than wildrye ($P = 0.088$) and at 57 DAP, aphid numbers were marginally higher in clover ($P = 0.075$) and wildrye ($P = 0.095$) than monoculture (Table 1).

A total of 1,002 leaf chewing insects across six families were captured during the study. The majority were species of leaf beetles (Chrysomelidae 81%) followed by weevils (Curculionidae 16%) which collectively accounted for 97% of leaf chewing insects captured. Most chrysomelid captures were flea beetles (tribe: Alticini 61%), followed by striped cucumber beetles (*Acalymma vittatum* 23%) and spotted cucumber beetles (*Diabrotica undecimpunctata*

8%). The leaf-chewing guild was mostly numerically similar among treatments during both years. An exception occurred in 2020, during the early plant stage (15 DAP: $\chi^2 = 11.87$, $df = 2$, $P = 0.002$) in which numbers were greater in monoculture than wildrye ($P = 0.022$).

A total of 35,393 leaf piercers were captured across 20 families. The most abundant leaf piercers were leafhoppers (Cicadellidae 51%), non-predatory thrips (order: Thysanoptera 29%), and aphids (Aphididae 13%) which collectively accounted for 93% of leaf piercers captured. In 2020, there was a treatment effect on numbers of leaf piercing herbivores during all three periods (15 DAP: $\chi^2 = 24.91$, $df = 2$, $P < 0.0001$, 39 DAP: $\chi^2 = 8.68$, $df = 2$, $P = 0.013$, 56 DAP: $\chi^2 = 16.75$, $df = 2$, $P = 0.0002$). There were greater numbers found in clover than monoculture during early ($P = 0.007$) and late ($P = 0.047$) season and numbers were higher in clover than wildrye during all three periods (early: $P = 0.004$, mid: $P = 0.04$ and late: $P = 0.008$; Table 2). In 2021, differences were detected during early (16 DAP: $\chi^2 = 31.63$, $df = 2$, $P < 0.0001$) and late season (57 DAP: $\chi^2 = 10.25$, $df = 2$, $P = 0.006$). Numbers were higher in clover than monoculture during early season ($P = 0.001$) and in clover than wildrye during early ($P = 0.005$) and late season ($P = 0.028$) (Table 3).

A total of 10,527 parasitic wasps were captured across 28 families. The most common parasitic wasp families captured were Platygasteridae (25%), Mymaridae (21%), Trichogrammatidae (14%), Encyrtidae (11%), Ceraphronidae (10%), Figitidae (7%) and Aphelinidae (5%) which collectively accounted for 95% of specimens captured on yellow sticky cards. In 2020, there was a significant treatment effect in the number of parasitic wasps captured during early-season (16 DAP, $\chi^2 = 8.33$, $df = 2$, $P = 0.016$). During this period, counts were marginally higher in clover than monoculture plots ($P = 0.054$; Table 2). In 2021, there was a significant treatment effect on parasitoid numbers during early (16 DAP: $\chi^2 = 19.98$, $df = 2$, $P < 0.0001$) and mid-season (37 DAP: $\chi^2 = 10.68$, $df = 2$, $P = 0.005$). During early season, parasitoid

numbers were greater in clover than monoculture ($P=0.008$) and Wildrye ($P=0.011$). However, during mid-season numbers were higher in monoculture than clover ($P=0.042$) and marginally higher in monoculture than wildrye ($P=0.053$; Table 3).

A total of 815 chewing predators across 13 families were captured during the study. The most common were ladybeetles (Coccinellidae 39%), rove beetles (Staphylinidae 28%), and ants (Formicidae 20%). These three families accounted for 87% of chewing predators captured. Differences among chewing predators only occurred in 2020 during mid ($\chi^2 = 13.52$, $df = 2$, $P=0.001$) and late ($\chi^2 = 6.46$, $df = 2$, $P=0.04$) season. In mid-season, there were more found in monoculture than clover ($P=0.014$). Also, during this period, numbers were marginally higher in monoculture than wildrye ($P=0.091$). In late season, numbers were marginally higher in clover than wildrye ($P=0.077$).

A total of 2,375 piercing predators were captured across 10 families during the study. The most abundant were minute pirate bugs (Anthocoridae, genus: Orius 44%), dance flies (Hybotidae 32%), stilt-legged flies (Dolichopodidae 12%) and big-eyed bugs (Geocoridae, genus: Geocoris 10%). These families accounted for 98% of piercing predators captured. In 2020, differences in piercing predators were found during early season (15 DAP: $\chi^2 = 23.44$, $df = 2$, $P<0.0001$). During this period, more were found in monoculture than wildrye ($P=0.005$) and wildrye than clover ($P=0.007$) (Table 2). In 2021, differences among treatments were found at all growth stages (16 DAP: $\chi^2 = 16.356$, $df = 2$, $P<0.0003$; day 37: $\chi^2 = 8.1$, $df = 2$, $P<0.018$; and day 57: $\chi^2 = 9.47$, $df = 2$, $P<0.009$). During early season numbers were higher in clover compared with monoculture ($P=0.012$) and wildrye ($P=0.022$) (Table 3).

Pitfall Traps - In 2020, there were no treatment differences in ground beetles, wolf spiders, rove beetles or feeding guild-level captures in pitfall traps. In 2021, a significant

treatment effect on ground beetle numbers was detected during the early stage (day 16: $\chi^2 = 10.37$, $df = 2$, $P < 0.006$). During this period, their numbers were higher in monoculture than wildrye ($P = 0.039$). Treatment differences among rove beetles were detected during early (day 16: $\chi^2 = 9.23$, $df = 2$, $P < 0.001$) and mid-season (day 37: $\chi^2 = 9.37$, $df = 2$, $P = 0.009$). During both periods, more rove beetles were found in clover than monoculture (day 16: $P = 0.038$, day 37: $P = 0.033$). Wolf spider numbers were higher in clover than wildrye during early season (day 16: $\chi^2 = 13.81$, $df = 2$, $P = 0.001$). Detritivores (which in this study includes fungivores) were the only feeding guild that differed among treatments. A total of 2,889 detritivores representing 36 families were captured. Most were field crickets (Gryllidae 63%) followed by scuttle flies (Phoridae 9%) and sap beetles (Nitidulidae 8%). These families accounted for 80% of the detritivores captured. In 2021, (day 16: $\chi^2 = 18.47$, $df = 2$, $P < 0.0001$) significantly more detritivores were captured in clover compared with monoculture and wildrye ($P = 0.012$) (Table 4).

Cantaloupe Yield - Treatment effects on fruit yield were detected during both years (2020: $F\text{-value} = 11.07$, $P = 0.004$, 2021; $F\text{-value} = 81.69$, $P < 0.0001$; Figure 3). In 2020, yield was 65% higher in monoculture than wildrye ($P = 0.003$). In 2021, yield in monoculture was 96 and 87% greater than clover and wildrye, respectively ($P < 0.0001$).

Cantaloupe Quality - In 2020, there was no treatment effect on the average weight, soluble solid content, or polar or equatorial diameter of fruit. However, treatment differences in firmness were detected ($F\text{-value} = 6.5$, $P = 0.033$), with fruit harvested from monoculture being

42% softer than fruit in wildrye ($P=0.003$) and 29% softer than clover which was marginally significant ($P=0.06$).

In 2020, fruit flesh hue angle in monoculture was 0.67% higher than clover ($P=0.0203$). In the Uniform Color Space (UCS) a color is redder the closer the hue angle is to 0° , yellower closer to 90° , greener closer to 180° , and bluer closer to 270° . The fruit flesh hue angle was $75.3^\circ \pm 0.1$ in monoculture and $74.8^\circ \pm 0.1$ in clover fruit, indicating the flesh in monoculture fruit was slightly yellower than fruit in the clover treatment, with monoculture fruit being slightly closer to red, or more orange (Table 5).

In 2021, more differences were detected among fruit quality parameters. Soluble solid content remained similar across treatments, however, differences were observed for weight (F-value=15.12, $P<0.0001$), polar circumference (F-value=7.82, $P=0.001$) and equatorial circumference (F-value=4.34, $P=0.012$). In monoculture, fruits were 22 and 30% heavier than in clover and wildrye, respectively. Their polar circumference in monoculture was 6.8 and 8.4% greater than clover and wildrye, respectively and their equatorial circumference in monoculture was 5.5 and 5.4% greater than clover and wildrye, respectively.

In 2021, differences existed between skin chroma (F-value=3.98, $P=0.020$), skin hue angle (F-value= 3.13, $P=0.046$), flesh chroma (F-value=9.9, $P<0.0001$), and flesh hue angle (F-value=5.73, $P=0.004$). Skin hue angle ($P=0.038$) and flesh chroma ($P=0.0005$) were 1.2% and 2.9% higher in clover than monoculture, respectively, and flesh hue angle ($P=0.007$) was 0.8% higher in monoculture. Higher chroma means that the color was brighter or more saturated in clover. The average skin hue angle was $90.5^\circ \pm 0.5$ in clover and $89.4^\circ \pm 0.3$ in monoculture, indicating these treatments displayed a similarly yellow hue, however, fruit skin was slightly more red in monoculture and slightly more green in clover. The average flesh hue angle was

75.1°±0.1 in monoculture and 74.5°±0.1 in clover, indicating that the fruit flesh in clover was more red or orange. Fruit in wildrye contained lower skin chroma ($P=0.017$), and flesh hue angle ($P=0.016$) than monoculture with skin chroma being 4.4% lower and flesh hue being 0.7% lower. The flesh hue angle in wildrye was 74.6°±0.1 indicating fruits were more red compared to monoculture. Flesh chroma was 2.9% higher in wildrye than monoculture ($P=0.0005$) (Table 5).

Discussion

The goal of this study was to determine if interplanting a living mulch with cantaloupe would result in fewer cucurbit pests and greater numbers of beneficial arthropods in cantaloupe plots; and to determine the response of arthropods to two structurally dissimilar living mulches. It was hypothesized that interplanting a living mulch into cantaloupe would result in a reduction in specialist cantaloupe herbivores and increased abundance of natural enemies. Though, some arthropods and feeding guilds conformed to this supposition, several had a neutral, inconsistent or aberrant response to the living mulch's presence and responded differently according to living mulch type. The striped cucumber beetle, a cucurbit specialist herbivore widely considered to be the most significant cantaloupe pests, appeared to be unaffected by the living mulches and consequently were found in similar numbers among cantaloupe habitats on most sampling dates. During several periods in both study years, greater number of leaf piercing herbivores including aphids were found on yellow sticky cards in cantaloupe interplanted with clover than wildrye and/or monoculture. However, no differences were detected among herbivore guilds within the cantaloupe foliage. With respect to natural enemies, spiders were one of the few natural enemy groups frequently influenced by the living mulch. They were found in greater abundance during visual counts in cantaloupe interplanted with clover than wildrye or monoculture plantings

during several sampling periods. Other natural enemy guilds such as parasitic wasps and piercing predators were inconsistently influenced by living mulch types.

Striped cucumber beetle numbers were similar among treatments on most sampling dates with the exception of a single sampling date in which beetles were less abundant in clover compared to other treatments. These results contrast past findings in other cucurbit systems in Maryland in which cucumber (*Cucumis sativus*) and zucchini (*Cucurbita pepo*) when interplanted with a red clover (*Trifolium pratense*) and sunn hemp (*Crotalaria juncea*) living mulch, respectively, resulted in reduced striped cucumber beetle numbers (Kahl et al. 2019; Hinds and Hooks 2013). In addition, Bach (1980) demonstrated in Michigan that striped cucumber beetle abundances were 10-30 times higher in monoculture cucumber compared to a polyculture system which included corn (*Zea mays*) and broccoli (*Brassica oleracea*). Bach (1980) determined that host plant diversity was a primary driver of differences in their abundance. Similarly, Cline et al., (2008) found reduced striped cucumber beetle numbers in watermelon (*Citrullus lanatus*) and cantaloupe (*Cucumis melo*) when grown with multiple companion plants, including Radish (*Raphanus sativus*), tansy (*Tanacetum vulgare*), nasturtium (*Tropaeolum* spp), or buckwheat (*Fagopyrum esculentum*), cowpeas (*Vigna unguiculata*) and sweet clover (*Melilotus officinalis*) in various combinations.

Striped cucumber beetle populations were consistently below the economic threshold level (Brust, 1999) in all treatments and didn't demonstrate any treatment effects. The earliest foliar detections of striped cucumber beetles were at 27 DAP in 2020, and 24 DAP in 2021 which is near the end of the 30 day period in which cantaloupe is considered most vulnerable to yield reduction due to insect inflicted damage (CMCC, 2003). In 2021, monoculture was the only treatment in which cucumber beetles were detected by 24 DAP while they were detected in

living mulch treatments a week later at 30 DAP. This delayed colonization in the living mulch habitats agrees with a central tenet of the resource concentration hypothesis (Root 1973). Still, these differences were not maintained throughout the cantaloupe agricultural cycle.

The most marked reductions in herbivore numbers in the living mulch systems was the reduction in alate aphids captured on sticky cards within the wildrye plots in 2021. In 2021, alate aphid numbers were 60 and 68% lower in wildrye than monoculture in early and late season respectively, though in the late season statistical significance was marginal. Reduction in aphid populations could be beneficial to cantaloupe due to the role species such as the green peach aphid (*Myzus persicae*) and melon aphid (*Aphis gossypii*) play in cantaloupe disease transmission (ATTRA, 2008; PUCES, 1998). Alate aphids respond to visual cues such as the contrast between bare soil and plants when selecting landing sites (Doring, 2014; Finch and Collier, 2001). Aphid abundances on sticky cards were greater in clover relative to monoculture in 2020. Though, the visibility of bare-ground was not quantified, it is probable that the wildrye, which is completely green and taller than clover, better obscured the cantaloupe plants from aphids. In contrast, clover may have behaved as a positive visual cue to alate aphids which resulted in higher aphid captures in clover than monoculture (Doring, 2014; Finch and Collier, 2001). Despite this, aphid counts within the cantaloupe foliage were similar among treatments.

In other studies, lower aphid counts were found in living mulch diversified cucurbit crops compared to monoculture. Hooks et al., (1998) found lower aphid numbers in zucchini interplanted with buckwheat (*Fagopyrum esculentum*) or yellow mustard (*Sinapis alba*), and Kahl et al., (2019) found lower numbers on cucumber interplanted with red clover. Costello (1994) also found that the leguminous living mulches white clover (*Trifolium repens*), strawberry clover (*Trifolium repens*) and a mixture of birdsfoot trefoil (*Lotus corniculatus*) and

red clover consistently lowered aphid infestations in broccoli in California while maintaining similar yields as monoculture plantings. The variation between living mulches' impact on aphids between these studies demonstrates the importance of evaluating various species of cover crops in different cropping systems as the response may differ according to living mulch and cash crop species.

There was a greater number of the leaf-piercing herbivore guild detected on yellow sticky cards in clover treatments during multiple periods. On average their numbers were 36.5% greater in clover than monoculture habitats. Most of this increase in clover can be attributed to greater number of leafhoppers, which on average were 54 and 53% higher in clover than monoculture and wildrye, respectively. However, leafhoppers are not a significant cucurbit pest (Bugg, 1991). As such, this could potentially be beneficial if an increase in economically benign herbivores supports greater natural enemy populations that subsequently help suppress economically important herbivores. Clovers typically produce a large amount of biomass and covers much of the soil surface. Relative to this, plant biomass has been shown to be correlated positively with arthropod herbivore abundance or biovolume through enhanced availability of resources (Marques et al. 2000). However, Hadaad et al., (2001) who identified a strong relationship between herbivores and plant biomass, found that sucking herbivores were considerably more responsive to plant species richness than biomass, in contrast to other feeding groups.

Though the presence of living mulch did not consistently result in increased populations of natural enemies as hypothesized, there were greater number of some natural enemy groups in living mulch treatments. For instance, foliar counts of spiders, and sticky card captures of parasitoids and piercing predators were greater in clover during several periods and rove beetles were significantly increased in clover during early and mid-season in 2021. Still, these

differences were not consistent among years and cantaloupe growth stage. Moreover, during some periods, counts of natural enemies were higher or equivalent in monoculture cantaloupe. Spiders had the most consistent response to living mulch in 2021, being higher in clover than monoculture on most sampling dates. Greater numbers of spiders detected in clover was consistent with the findings of Costello and Daane (1998), Hooks and Johnson (2007) and Snyder (2019). Further, a review conducted by Sunderland and Samu (2000) documented that spider numbers are generally greater in more vegetative complex agroecosystems. No natural enemies were found in greater numbers in wildrye compared to monoculture. However, other perennial grasses in the form of beetle banks and riparian buffers have been shown to support increased natural enemies including ground beetles, rove beetles, and ground dwelling spiders, especially wolf spiders and sheet weavers (Linyphiidae) (MacLeod, 2004; Nelson et al., 2018).

In both years, monoculture cantaloupe had significantly higher marketable yield compared to wildrye and in 2021 marketable yields were also higher compared to clover. The yield differences in 2021 were more pronounced compared to 2020. The more marked differences may have been due to increased competition with more densely planted living mulch plots. In 2019, the clover and wildrye were seeded at rates of ~ 7 and 17 kg/ha, respectively for the 2020 season; and in 2020, the seeding rate for each was increased to ~ 9 and 25 kg/ha for the clover and wildrye, respectively. In 2021, fruits in monoculture were 22 and 30% heavier than in clover and wildrye, respectively, which contributed to the greater marketable yield in monoculture.

Fruit color and texture also differed among treatments. In 2020, fruits in living mulch treatments (wildrye 42% and clover 29%) were firmer than in monoculture. Higher firmness has been shown to make fruit such as melons less desirable to consumers (Shewfelt 1999; Lester

2006). Detectable differences in color were usually within a degree among treatments. Ripe cantaloupe skin appearance varies according to cultivar but most, including sugar cube, turn a shade of light yellow in addition to developing webbing on their rind (Almela and Fernandez-Lopez, 2000). Yellow is characterized by a hue angle of 90° in the Uniform Color Space, and no treatments contained fruits that deviated more than 0.6° from the yellow axis of the UCS during either study year. Flesh hue was similarly consistent, with no treatment deviating more than 0.5° from 75° (appearing as a yellow-orange) during either year. Still, fruits in the living mulch treatments contained a slightly lower hue angle than monoculture and more precisely were half a degree closer to the red axis in 2021. The flesh chroma of the living mulch treatments was nearly 3% higher than monoculture, meaning the color was slightly more saturated. However, skin chroma was roughly 4.4% higher in monoculture than wildrye, which would be more likely noticeable by a prospective consumer.

Cantaloupe begins to soften and change color rapidly during ripening, and it is possible that slight differences in ripeness could contribute to differences in softness and color (Lester & Dunlap, 1985; Almela and Fernandez-Lopez, 2000). However, it is worth noting that soluble solid content, another important indicator of fruit ripeness, was identical across all treatments throughout the study and remained within the 10-12% range needed to be considered marketable (Almela and Fernandez-Lopez, 2000). Measured differences in flesh and skin color between treatments were subtle enough that consumers might not perceive a difference in color between fruit, though the most visible difference in fruit color was the saturation of skin color between the monoculture and wildrye treatments. The duller skin color of fruit grown in wildrye, along with increased firmness in 2020 and reduced size in 2021 observed in the living mulch treatments may diminish the desirability of such cantaloupe to consumers (Shewfelt 1999; Lester

2006). However, sugar cube is specifically bred and marketed as a smaller cultivar ideal for individual consumption, so somewhat reduced size might not be considered a negative trait to consumers seeking a smaller melon.

Though increasing the seeding rate of living mulches can result in greater competition and an associated yield reduction, the greater cover crop biomass could result in greater weed suppression in the between row areas. Potential modifications to reduce competition with cash crops without abating the weed suppression benefit in the inter-row areas could involve reducing the strip width of the living mulches and/or, cutting the living mulch closer to the ground prior to cash crop planting. However, the impact of these changes on the arthropod assemblages should be considered. For example, during the final year of a three-year study, Hinds and Hooks (2013) cut the sunn hemp living mulch to a significantly lower height from previous years to reduce early season competition with the zucchini transplants, this resulted in yields being significantly higher in sunn hemp compared to monoculture zucchini at one of the study sites compared to earlier study years (Hinds and Hooks 2015). However, it was believed that the change in sunn hemp height eliminated the cucumber beetle suppression benefit observed during earlier study years.

The current study highlights the importance of investigating different living mulch and cash crops systems in disparate regions. Multiple studies have shown that living mulches have the potential to reduce pests and improve yield in various cropping systems, including cucurbits. Nevertheless, these results are not always transferable to different agroecosystems and regions. Despite the living mulch systems used in this study not delivering a significant effect on major cantaloupe herbivores or marketable yield benefit, this study helps elucidate the potential limitations of using living mulches to manipulate arthropods in cantaloupe. Still, through

refinement of the system, alsike clover and Virginia wildrye may be of benefit if their negative impact on yield can be solved and their presence suppresses weeds in the inter-row areas. Alternatively, other species of living mulches may confer such a benefit without reducing cantaloupe yield. To this end, future studies should consider concomitantly examining the impact of interplanted living mulches on multiple pest complexes and examining different living mulch species in cantaloupe plantings.

Table 1: Mean number of striped cucumber beetles (*Acalymma vitattum*) and aphids (family: aphididae) ($\pm$ SE) captured on sticky cards in monoculture and living mulch interplanted plots during three periods of the cantaloupe agricultural cycle.

Year	Taxa	Period	Treatment ($\pm$ SE)		
			Monoculture	Clover	Wildrye
2020	<i>A. vitattum</i>	Early	-	-	-
		Mid	2.8 $\pm$ 1.0	1.1 $\pm$ 0.4	0.9 $\pm$ 0.4
		Late	3.0 $\pm$ 0.7	1.9 $\pm$ 0.5	2.0 $\pm$ 0.6
	Aphididae	Early	44.8 $\pm$ 5.6	33.1 $\pm$ 3.1	33.6 $\pm$ 4.8
		Mid	16.1 $\pm$ 1.3 ab	22.3 $\pm$ 2.9 a	11.4 $\pm$ 2.4 b
		Late	97.6 $\pm$ 13.0 ab	115.5 $\pm$ 12.6 a	58.4 $\pm$ 13.7 b
2021	<i>A. vitattum</i>	Early	-	-	-
		Mid	1.4 $\pm$ 0.6	1.0 $\pm$ 0.4	1.8 $\pm$ 0.7
		Late	5.4 $\pm$ 1.3	3.4 $\pm$ 0.9	4.1 $\pm$ 1.0
	Aphididae	Early	21.0 $\pm$ 3.3 a	11.4 $\pm$ 1.8 b*	8.3 $\pm$ 2.4 b
		Mid	17.9 $\pm$ 2.5 ab	25.1 $\pm$ 2.8 a	15.4 $\pm$ 1.9 b
		Late	22.0 $\pm$ 4.8 a*	23.0 $\pm$ 4.0 a	7.3 $\pm$ 2.5 b

Different letters indicate significant differences among treatments ($P < 0.05$).

* Denotes significance as marginal ($0.05 \leq P < 0.1$)

Table 2: Mean number of arthropods ($\pm$ SE) by feeding guild found on sticky cards in monoculture and living mulch interplanted plots during three periods of the cantaloupe agricultural cycle in 2020

Feeding guild	Period	Treatment ($\pm$ SE)		
		Monoculture	Clover	Wildrye
Leaf chewers	Early	10.1 $\pm$ 1.9 a	5.1 $\pm$ 0.7 b*	3.3 $\pm$ 0.6 b
	Mid	14.5 $\pm$ 1.4	10.1 $\pm$ 1.6	16.6 $\pm$ 2.9
	Late	6.3 $\pm$ 1.6	7.8 $\pm$ 1.2	7.0 $\pm$ 0.9
Leaf piercers	Early	128.1 $\pm$ 11.4 a	212.0 $\pm$ 15.1 b	119.7 $\pm$ 12.6 a
	Mid	191.5 $\pm$ 12.9 ab	219.5 $\pm$ 19.6 a	150.8 $\pm$ 12.6 b
	Late	287.6 $\pm$ 19.2	359.5 $\pm$ 10.9	258.6 $\pm$ 20.7
Parasitoids	Early	38.6 $\pm$ 4.7 a	58.6 $\pm$ 3.9 b*	42.9 $\pm$ 2.5 ab
	Mid	102.3 $\pm$ 6.5	123.8 $\pm$ 8.9	98.3 $\pm$ 7.3
	Late	58.3 $\pm$ 7.6	66.3 $\pm$ 5.8	66.5 $\pm$ 8.6
Chewing predators	Early	12.3 $\pm$ 4.6	5.2 $\pm$ 1.1	6.3 $\pm$ 2.0
	Mid	13.0 $\pm$ 2.7 a	4.0 $\pm$ 0.8 b	7 $\pm$ 1.2 b*
	Late	3.6 $\pm$ 0.9 a	2.6 $\pm$ 0.6 b	5.3 $\pm$ 0.7 a*
Sucking predators	Early	5.4 $\pm$ 1.1 a	17 $\pm$ 2.9 b	6.1 $\pm$ 1.0 a
	Mid	30.5 $\pm$ 2.3	31.1 $\pm$ 2.7	23.9 $\pm$ 3.0
	Late	15.4 $\pm$ 1.1 a	19.5 $\pm$ 2.4 ab	24 $\pm$ 2.8 b*

Different letters indicate significant differences among treatments ($P < 0.05$).

* Denotes significance as marginal ($0.05 \leq P < 0.1$)

Table 3: Mean number of arthropods ($\pm$ SE) by feeding guild found on sticky cards in monoculture and living mulch interplanted plots during three periods of the cantaloupe agricultural cycle in 2021.

Feeding guild	Period	Treatment ($\pm$ SE)		
		Monoculture	Clover	Wildrye
Leaf chewers	Early	3.3 $\pm$ 0.8	4.4 $\pm$ 0.9	6.0 $\pm$ 1.3
	Mid	8.6 $\pm$ 1.6	10.9 $\pm$ 1.1	12.1 $\pm$ 3.2
	Late	9.5 $\pm$ 1.2	10.3 $\pm$ 1.4	8.1 $\pm$ 2.3
Leaf piercers	Early	163.8 $\pm$ 17.2 a	344.4 $\pm$ 32.1 b	197.3 $\pm$ 20.7 a
	Mid	264.3 $\pm$ 18.9	327.1 $\pm$ 26.8	244.6 $\pm$ 22.7
	Late	332.9 $\pm$ 29.6 ab	404.0 $\pm$ 60.0 a	218.0 $\pm$ 25.5 b
Parasitoids	Early	51.4 $\pm$ 3.9 a	83.5 $\pm$ 8.2 b	52.8 $\pm$ 3.5 a
	Mid	112.3 $\pm$ 11.4 a	80.3 $\pm$ 4.3 b	81.9 $\pm$ 5.9 b
	Late	65.6 $\pm$ 5.8	60.3 $\pm$ 10.9	72.6 $\pm$ 4.4
Chewing predators	Early	9.3 $\pm$ 2.3	7.5 $\pm$ 1.4	6.1 $\pm$ 1.4
	Mid	3.3 $\pm$ 0.6	2.0 $\pm$ 0.3	2.0 $\pm$ 0.5
	Late	4.9 $\pm$ 0.7	3.9 $\pm$ 0.9	3.6 $\pm$ 1.4
Sucking predators	Early	8.8 $\pm$ 2.0 a	24.5 $\pm$ 3.6 b	10.9 $\pm$ 3.2 a
	Mid	12.3 $\pm$ 1.6 a	19.8 $\pm$ 3 b*	13.1 $\pm$ 0.9 ab
	Late	14.0 $\pm$ 2.0 a	14.0 $\pm$ 2.4 a	6.8 $\pm$ 1.1 b

Different letters indicate significant differences among treatments ($P < 0.05$).

* Denotes significance as marginal ($0.05 \leq P < 0.1$)

Table 4: Mean number of epigeal predators ($\pm$ SE) by family found in pitfall traps in monoculture and living mulch interplanted plots during three periods of the cantaloupe agricultural cycle in 2020 and 2021.

Year	Family	Period	Treatment ($\pm$ SE)		
			Monoculture	Clover	Wildrye
2020	Lycosidae	Early	0.8 $\pm$ 0.4	1.6 $\pm$ 0.6	1.0 $\pm$ 0.4
		Mid	0.0 $\pm$ 0.0	0.6 $\pm$ 0.3	0.1 $\pm$ 0.1
		Late	0.7 $\pm$ 0.4	0.8 $\pm$ 0.3	0.0 $\pm$ 0.0
	Carabidae	Early	2.9 $\pm$ 1.0	1.3 $\pm$ 0.9	0.5 $\pm$ 0.3
		Mid	0.8 $\pm$ 0.3	0.1 $\pm$ 0.1	0.4 $\pm$ 0.3
		Late	0.3 $\pm$ 0.2	0.9 $\pm$ 0.3	0.5 $\pm$ 0.4
	Staphylinidae	Early	0.3 $\pm$ 0.3	0.8 $\pm$ 0.5	0.0 $\pm$ 0.0
		Mid	0.4 $\pm$ 0.2	1.3 $\pm$ 0.8	0.6 $\pm$ 0.4
		Late	2.6 $\pm$ 0.8	2.6 $\pm$ 1.2	1.8 $\pm$ 0.7
2021	Lycosidae	Early	1.6 $\pm$ 0.3 a*	2.1 $\pm$ 0.4 a	0.4 $\pm$ 0.3 b
		Mid	1.4 $\pm$ 0.5	1.3 $\pm$ 0.5	1.0 $\pm$ 0.8
		Late	0.6 $\pm$ 0.3	1.3 $\pm$ 0.5	0.25 $\pm$ 0.2
	Carabidae	Early	8.0 $\pm$ 2.0 a	2.5 $\pm$ 0.7 b*	1.8 $\pm$ 0.5 b
		Mid	3.1 $\pm$ 1.0	1.9 $\pm$ 0.7	1.5 $\pm$ 0.5
		Late	3.1 $\pm$ 0.8	2.1 $\pm$ 0.6	7.5 $\pm$ 2.2
	Staphylinidae	Early	1.6 $\pm$ 0.5 a	32.1 $\pm$ 11.6 b	13.4 $\pm$ 2.3 ab
		Mid	2.0 $\pm$ 0.9 a	12.8 $\pm$ 3.7 b	7.1 $\pm$ 1.9 ab
		Late	4.0 $\pm$ 1.2	13.5 $\pm$ 4.6	26.3 $\pm$ 11.2

Different letters indicate significant differences among treatments ($P < 0.05$).

* Denotes significance as marginal ($0.05 \leq P < 0.1$)

Table 5: Mean value of different cantaloupe fruit quality metrics ($\pm$ SE) by treatment.

Year	Metric	Treatment ($\pm$ SE)		
		Monoculture	Clover	Wildrye
2020	Weight (g)	1559.2 $\pm$ 51.9	1456.2 $\pm$ 61.8	1458.3 $\pm$ 48.6
	Polar circum (cm)	46.6 $\pm$ 0.6	45.4 $\pm$ 0.7	45.7 $\pm$ 0.5
	Equator circum (cm)	44.9 $\pm$ 0.4	44.7 $\pm$ 0.5	45.0 $\pm$ 0.6
	Soluble solids (%)	11.4 $\pm$ 0.3	11.4 $\pm$ 0.2	11.0 $\pm$ 0.3
	Firmness (N)	970.9 $\pm$ 66.9 a	1306 $\pm$ 113.8 b*	1488.9 $\pm$ 120.1 b
	Skin chroma (C*)	34.0 $\pm$ 0.3	33.4 $\pm$ 0.4	33.1 $\pm$ 0.5
	Skin hue angle (h)	90.3 $\pm$ 0.3	90.2 $\pm$ 0.3	89.6 $\pm$ 0.3
	Flesh chroma (C*)	43.4 $\pm$ 0.3	44.4 $\pm$ 0.3	44.2 $\pm$ 0.4
	Flesh hue angle (h)	75.3 $\pm$ 0.1	74.8 $\pm$ 0.1	75.2 $\pm$ 0.1
2021	Weight (g)	1443.4 $\pm$ 39.8 a	1162.5 $\pm$ 61.6 b	1064.5 $\pm$ 48.6 b
	Polar circum (cm)	45.4 $\pm$ 0.5 a	42.4 $\pm$ 0.8 b	41.7 $\pm$ 0.8 b
	Equator circum (cm)	43.8 $\pm$ 0.5 a	41.4 $\pm$ 0.6 b	41.4 $\pm$ 0.8 b
	Soluble solids (%)	10.0 $\pm$ 0.2	10.9 $\pm$ 0.6	10.6 $\pm$ 0.2
	Firmness (N)	2094.1 $\pm$ 236.5	2019.2 $\pm$ 133	1765.6 $\pm$ 115.8
	Skin chroma (C*)	34.8 $\pm$ 0.4 a	33.7 $\pm$ 0.4 ab	33.3 $\pm$ 0.4 b
	Skin hue angle (h)	89.4 $\pm$ 0.3 a	90.5 $\pm$ 0.3 b	89.8 $\pm$ 0.3 ab
	Flesh chroma (C*)	43.6 $\pm$ 0.3 a	44.9 $\pm$ 0.3 b	44.9 $\pm$ 0.3 b
	Flesh hue angle (h)	75.1 $\pm$ 0.1 a	74.5 $\pm$ 0.1 b	74.6 $\pm$ 0.1 b

Different letters indicate significant differences among treatments ($P < 0.05$).

* Denotes significance as marginal ($0.05 \leq P < 0.1$)

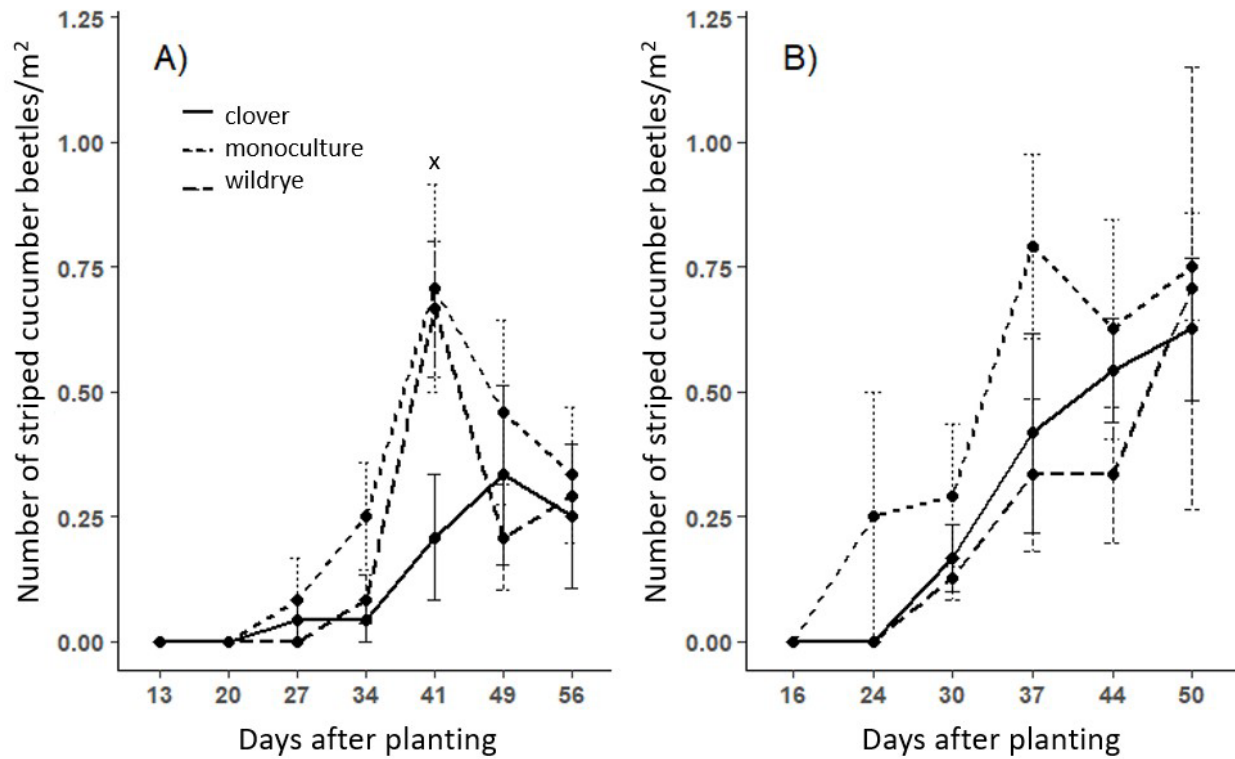


Figure 1: Mean densities ($\pm$ SE) of striped cucumber beetles (*Acalymma vittatum*) found within the cantaloupe foliage in monoculture and Virginia wildrye (wildrye) and alsike clover (clover) interplanted treatments during the 2020 (A) and 2021 (B) field seasons. Letter x indicates densities in monoculture and wildrye are greater than clover ($P < 0.05$).

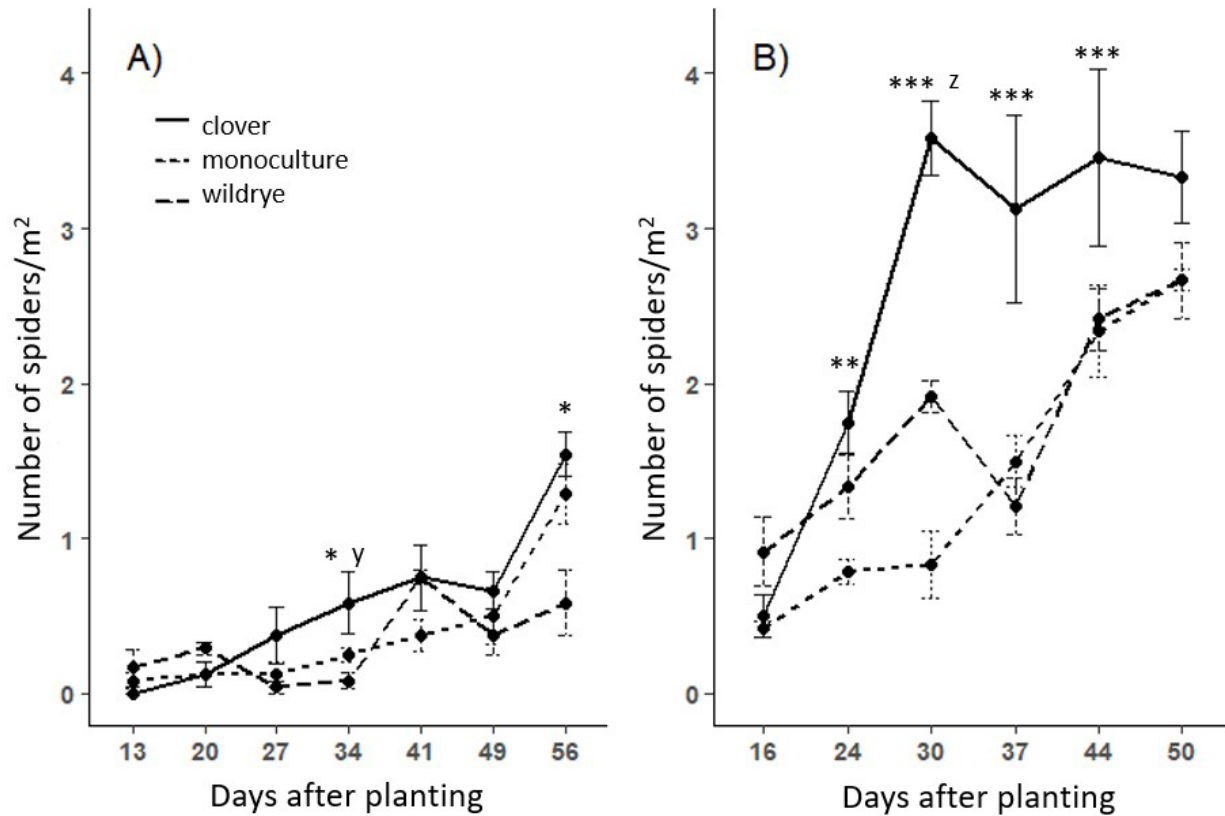


Figure 2: Mean densities ($\pm$ SE) of spiders (order: Araneae) found within the cantaloupe foliage in monoculture and Virginia wildrye (wildrye) and alsike clover (clover) interplanted treatments during the 2020 (A) and 2021 (B) field seasons. The letter y indicates densities are greater in monoculture than wildrye; * indicates densities are greater in clover than wildrye; ** indicates densities greater in clover than monoculture; *** indicates densities greater in clover than monoculture and wildrye; and z indicates densities in wildrye greater than monoculture and less than clover ($P < 0.05$).

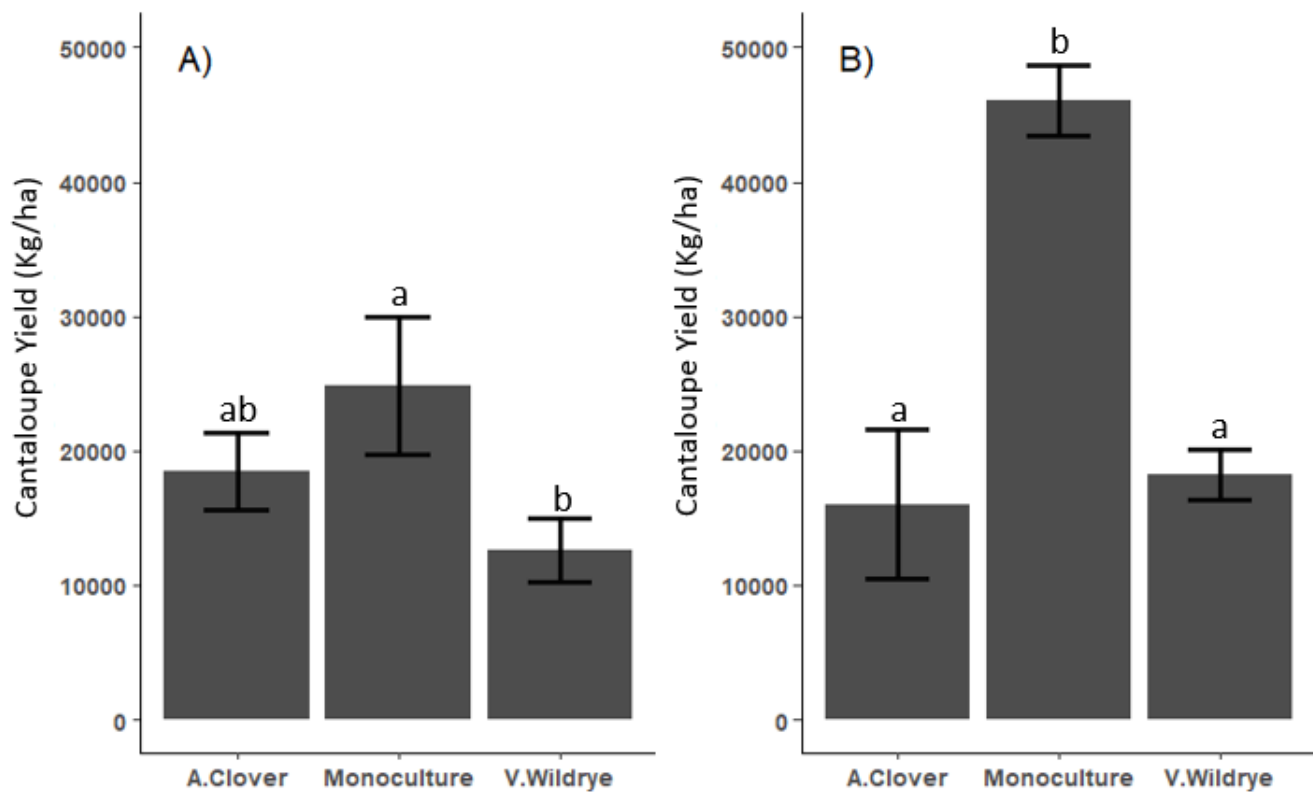


Figure 3: Mean cantaloupe marketable yield ($\pm$ 95% CI) by treatment during the 2020 (A) and 2021 (B) field seasons. Different letters indicate significant differences among treatments ($P < 0.05$).

References Cited

- ATTRA. (2008).** Cucumber Beetles: Organic and Biorational Integrated Pest Management. — National Sustainable Agriculture Information Service, p. 5.
- de Alckmin Marques, E. S., Price, P. W., & Cobb, N. S. (2000).** Resource abundance and insect herbivore diversity on woody fabaceous desert plants. *Environmental Entomology*, 29(4), 696–703. <https://doi.org/10.1603/0046-225x-29.4.696>
- Almela, L.; Sanchez, C.; Fernandez-Lopez, J.A.; Romojaro, F. (2000).** Note. Non-destructive appraisal of the ripeness in Cantaloupe melons / Nota. Evaluacion no destructiva de la madurez en melones Cantaloupe. *Food Science and Technology International*, 6(1), 47–51. doi:10.1177/108201320000600107
- Arnett Jr, Ross H., and Michael C. Thomas, eds. 2000.** American Beetles: Archostemata, Myxophaga, Adephaga, Polyphaga: Staphyliniformia. Vol. 1. CRC Press
- Bach, C. E. 1980.** Effects of plant-density and diversity on the population-dynamics of a specialist herbivore, the striped cucumber beetle *Acalymma vittata*. *Ecology* 61: 1515–1530.
- Beaulieu, J.C., Ingram, D.A., Lea, J.M., Bett-Garber, K.L., 2004.** Effect of harvest maturity on the sensory characteristics of fresh-cut cantaloupe. *Journal of Food Science*, 69 (7), S250–S258
- Bouzayen, M., Latché, A., Nath, P., Pech, J.C., 2010.** Mechanism of fruit ripening. *Plant Developmental Biology-biotechnological Perspectives*. Springer, pp. 319–339.
- Bowers, C., Toews, M., Liu, Y., & Schmidt, J. M. 2020.** Cover crops improve early season natural enemy recruitment and pest management in cotton production. *Biological*

- Control, 141. <https://doi.org/10.1016/j.biocontrol.2019.104149>
- Brummell, D.A., Harpster, M.H., 2001.** Cell wall metabolism in fruit softening and quality and its manipulation in transgenic plants. *Plant Molecular Biology*, 47, 311–340
- Brust, G. E., & Foster, R. E. 1999.** New economic threshold for striped cucumber beetle (Coleoptera: Chrysomelidae) in cantaloupe in the Midwest. *Journal of Economic Entomology*, 92(4), 936–940. <https://doi.org/10.1093/jee/92.4.936>
- Brust, J. 2017.** Mild winter induces three vegetable pest problems, Greenh. TPM / IPM Bi-Wkly. Rep. Ellicott City, Maryland
- Bugg, R. L. 1991.** Cover crops and control of arthropod pests of agriculture. *Pest Control*. 157–165.
- Burger, Y., Saar, U., Paris, H.S., Lewinsohn, E., Katzir, N., Tadmor, Y., Schaffer, A.A., 2006.** Genetic variability for valuable fruit quality traits in *Cucumis melo* Israel Journal of Plant Science, 54, 233–242
- CIE 2004,** Technical Report: Colorimetry, International Commission on Illumination, CIE 15 (3)
- Cline, G. R., J. D. Sedlacek, S. L.Hillman, S. K. Parker, and A. F. Silvernail. 2008.** Organic management of cucumber beetles in watermelon and muskmelon production. *Hort Technology*. 18: 436–444.
- CMCC. 2003.** Pest Management Strategic Plan for Cantaloupe , Honeydew, and Mixed Melon Production in California. (April), 1–7

- Costello, M. J. 1994.** Broccoli growth, yield and level of aphid infestation in leguminous living mulches. *Biological Agriculture and Horticulture*, 10(3), 207–222.
<https://doi.org/10.1080/01448765.1994.9754669>
- Costello, M. J., & Daane, K. M. 1998.** Influence of ground cover on spider populations in a table grape vineyard. *Ecological Entomology*, 23(1), 33–40.
<https://doi.org/10.1046/j.1365-2311.1998.00108.x>
- Döring, T. F. 2014.** How aphids find their host plants, and how they don't. In *Annals of Applied Biology* (Vol. 165, Issue 1, pp. 3–26). Blackwell Publishing Ltd.
<https://doi.org/10.1111/aab.12142>
- Farciuh, M., Copes, B., Le-Navenec, G., Marroquin, J., Cantu, D., Bradford, K. J., Guinard, J. X., & van Deynze, A. 2020a.** Sensory, physicochemical and volatile compound analysis of short and long shelf-life melon (*Cucumis melo* L.) genotypes at harvest and after postharvest storage. *Food Chemistry: X*, 8.
<https://doi.org/10.1016/j.fochx.2020.100107>
- Farciuh, M., Copes, B., Le-Navenec, G., Marroquin, J., Jaunet, T., Chi-Ham, C., Cantu, D., Bradford, K. J., & van Deynze, A. 2020b.** Texture diversity in melon (*Cucumis melo* L.): Sensory and physical assessments. *Postharvest Biology and Technology*, 159.
<https://doi.org/10.1016/j.postharvbio.2019.111024>
- Finch, S., and R. H. Collier. 2001.** Host plant finding by insects - undersowing crop plants with clover reveals the missing link. *Proc. 4th Int. Work.* 45–50
- Gallitelli, D. 2000.** The ecology of Cucumber mosaic virus and sustainable agriculture. *Virus Research*, 71(1–2), 9–21. [https://doi.org/10.1016/S0168-1702\(00\)00184-2](https://doi.org/10.1016/S0168-1702(00)00184-2)

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., ...

Inchausti, P. (2010). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology*, 11(2), 97–105. <https://doi.org/10.1016/j.baae.2009.12.001>

Giovannoni, J.J., 2004. Genetic regulation of fruit development and ripening. *Plant Cell* 16, S170–S180.

Haddad, N. M., Tilman, D., Haarstad, J., Ritchie, M., and Knops, J. M.H. 2001. "Contrasting Effects of Plant Richness and Composition on Insect Communities: A Field Experiment". *The American Naturalist*, 158(1), 17-35

Hinds, J., & Hooks, C. R. R. 2013. Population dynamics of arthropods in a sunn-hemp zucchini interplanting system. *Crop Protection*, 53, 6–12.
<https://doi.org/10.1016/j.cropro.2013.06.003>

Hinds, J., Wang, K. H., & Hooks, C. R. R. 2015. Growth and yield of zucchini squash (*Cucurbita pepo* L.) as influenced by a sunn hemp living mulch. *Biological Agriculture and Horticulture*, 32(1), 21–33. <https://doi.org/10.1080/01448765.2015.1017736>

Hooks, C. R. R., H. R. Valenzuela, and J. Defrank. 1998. Incidence of pests and arthropod natural enemies in zucchini grown with living mulches. *Agric. Ecosyst. Environ.* 69: 217–231

Hooks, C., Pandey, R. R., & Johnson, M. W. 2007. Using Clovers as Living Mulches to Boost Yields, Suppress Pests, and Augment Spiders in a Broccoli Agroecosystem.
<http://www.ctahr.hawaii.edu/freepubs>

- Kahl, H. M., Leslie, A. W., & Hooks, C. R. R. 2019.** Effects of Red Clover Living Mulch on Arthropod Herbivores and Natural Enemies, and Cucumber Yield. *Annals of the Entomological Society of America*, 112(4), 356–364. <https://doi.org/10.1093/aesa/say036>
- Lester, G.E., 2006.** Consumer preference quality attributes of melon fruits. *Acta Horticulturae*, 712, 175–182
- Lester, G. E., & Dunlap, J. R. 1985.** Physiological changes during development and ripening of ‘Perlita’ muskmelon fruits. *Scientia Horticulturae*, 26(4), 323–331.
[https://doi.org/10.1016/0304-4238\(85\)90016-0](https://doi.org/10.1016/0304-4238(85)90016-0)
- MacLeod, A., Wratten, S. D., Sotherton, N. W., & Thomas, M. B. 2004.** “Beetle banks” as refuges for beneficial arthropods in farmland: Long-term changes in predator communities and habitat. *Agricultural and Forest Entomology*, 6(2), 147–154.
<https://doi.org/10.1111/j.1461-9563.2004.00215.x>
- Marsh, Paul M. 1994.** "Hymenoptera of the world: an identification guide to families." *American Entomologist* 40.2: 115-116.
- Marshall, Stephen A. 2006.** *Insects: their natural history and diversity: with a photographic guide to insects of eastern North America.* Buffalo, NY: Firefly Books
- Marshall, Stephen A. 2012.** *Flies: the natural history and diversity of Diptera.* Firefly Books, Buffalo, New York and Richmond Hill, Ontario, 616 pp.
- Marshall, Stephen A. 2018.** *Beetles: The natural history and diversity of Coleoptera.* Firefly Books (US) Incorporated
- Metcalf, R. L., & Metcalf, E. R. 1992.** *Plant kairomones in insect ecology and control.*
Retrieved from <https://www.cabdirect.org/cabdirect/abstract/19941101448>

Mitchell, R. F., & Hanks, L. M. 2009. Insect Frass as a Pathway for Transmission of Bacterial Wilt of Cucurbits. *Environmental Entomology*, 38(2), 395–403.

<https://doi.org/10.1603/022.038.0212>

Nelson, J. L., Hunt, L. G., Lewis, M. T., Hamby, K. A., Hooks, C. R. R., & Dively, G. P.

2018. Arthropod communities in warm and cool grass riparian buffers and their influence

Nerson, H. 1989. Weed competition in muskmelon and its effects on yield and fruit quality.

Crop Protection, 8.

Obando-Ulloa, J.M., Eduardo, I., Monforte, A.J., Fernandez-Trujillo, J.P., 2009.

Identification of QTLs related to sugar and organic acid composition in melon using near-isogenic lines. *Scientia Horticulturae*, 121 (4), 425–433

Osorio, S., Fernie, A.R., 2013. Biochemistry of fruit ripening. In: Seymour, G.B., Poole,

M., Giovannoni, J.J., Tucker, G.A. (Eds.), *The Molecular Biology and Biochemistry of Fruit Ripening*. John Wiley & Sons Inc., Iowa, pp. 1–19.

Pickett, J. A., Woodcock, C. M., Midega, C. A. O., & Khan, Z. R. 2014. Push-pull farming systems. *Current Opinion in Biotechnology*, 26, 125–132.

<https://doi.org/10.1016/j.copbio.2013.12.006>

Relyea, R. A. 2016. The Impact of Insecticides and Herbicides on the Biodiversity and

Productivity of Aquatic Communities Author (s): Rick A . Relyea Published by : Wiley

Stable URL : <http://www.jstor.org/stable/4543379> Accessed : 15-04-2016 01 : 19 UTC

Your use of the JST. 15(2), 618–627.

Root, R. B. 1973. Organization of a plant-arthropod association in simple and diverse habitats:

the fauna of collards (*Brassica oleracea*). *Ecological Monographs*. 43: 95–124

- Jr., Ross H. Arnett, et al. 2002.** American beetles, volume II: Polyphaga: Scarabaeoidea through Curculionoidea. CRC Press
- Saladie, M., Matas, A.J., Isaacson, T., Jenks, M., Goodwin, S.M., Niklas, K., Xiaolin, R., Labavitch, J., Shackel, K., Fernie, A., Lytovchenko, A., O'Neill, M., Watkins, C.B., Rose, J.K.C., 2007.** A reevaluation of the key factors that influence tomato fruit softening and integrity. *Plant Physiology*, 144, 1012–1028.
- Schmidt, N. P., Neal, M. E. O., & Singer, J. W. 2007.** Alfalfa Living Mulch Advances Biological Control of Soybean Aphid. (O'Neill 2005), 416–424.
- Seymour, G.B., Østergaard, L., Chapman, N.H., Knapp, S., Martin, S., 2013.** Fruit development and ripening. *Annual Review of Plant Biology* 64, 219–241
- Shackel, K.A., Greve, C., Labavitch, J.M., Ahmadi, H., 1991.** Cell turgor changes associated with ripening in tomato pericarp tissue. *Plant Physiology*, 97, 814–816
- Shelton, D. R., A. M. Sadeghi, and A. R. Isensee. 1993.** Estimation of granular carbofuran dissolution rates in soil. *J. Agric. Food Chemistry*. 41: 1134–1138
- Shewfelt, R.L., 1999.** What is quality? *Postharvest Biology and Technology*. 15, 197–200
- Snyder, W. E. 2019.** Give predators a complement: Conserving natural enemy biodiversity to improve biocontrol. *Biological Control*, 135(April), 73–82.
<https://doi.org/10.1016/j.biocontrol.2019.04.017>
- Snyder, W. E., & Wise, D. H. 2000.** Antipredator Behavior of Spotted Cucumber Beetles (Coleoptera: Chrysomelidae) in Response to Predators That Pose Varying Risks. *Environmental Entomology*, 29(1), 35–42. <https://doi.org/10.1603/0046-225x-29.1.35>

- Sunderland, K., & Samu, F. (2000).** Effects of agricultural diversification on the abundance, distribution, and pest control potential of spiders: a review. In *Entomologia Experimentalis et Applicata* (Vol. 95).
- Triplehorn, Charles A., Norman F. Johnson, and Donald Joyce Borror. 2005.** Borror and DeLong's Introduction to the Study of Insects. No. QL463 B69 2005.
- Usenik, V., Kastelec, D., Veberic, R., Stampar, F., 2008.** Quality changes during ripening of plums (*Prunus domestica* L.). *Food Chemistry*, 111, 830–836.
- Van der Sluijs, J. P., Simon-Delso, N., Goulson, D., Maxim, L., Bonmatin, J. M., & Belzunces, L. P. 2013.** Neonicotinoids, bee disorders and the sustainability of pollinator services. *Current Opinion in Environmental Sustainability*, 5(3–4), 293–305.
<https://doi.org/10.1016/j.cosust.2013.05.007>
- Wang, K.-Y., T.-X. Liu, C.-H. Yu, X.-Y. Jiang, and M.-Q. Yi. 2002.** Resistance of *Aphis gossypii* (Homoptera: Aphididae) to fenvalerate and imidacloprid and activities of detoxification enzymes on cotton and cucumber. *J. Economic Entomology*. 95: 407–413.
- Weisenburger, D. D. 1993.** Human health effects of agrichemical use. *Human Pathology*, 24(6), 571–576. [https://doi.org/10.1016/0046-8177\(93\)90234-8](https://doi.org/10.1016/0046-8177(93)90234-8)
- Williams, J. L., W. E. Snyder, and D. H. Wise. 2001.** Sex-based differences in antipredator behavior in the spotted cucumber beetle (Coleoptera: Chrysomelidae). *Environmental Entomology*. 30: 327–332