The Effects of Farmscaping Plants on the Abundance, Diversity, and Longevity of Arthropods in Organic Tomato Fields in Alabama

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Abstract

Organic farming is the practice of cultivating crops without the use of synthetic pesticides or fertilizers. Farmscaping is habitat manipulation system of planting plants near the crop to attract beneficial insects by providing food or shelter resources. This study evaluated the effects of planting sunflower, sweet alyssum, buckwheat, and licorice mint around organic tomato fields on the abundance and diversity of insects in the fields. We tested the effects of sweet alyssum, buckwheat, and licorice mint on the nutrient levels and longevity of a parasitoid wasp, *Microplitis croceipes* (Cresson) (Hymenoptera: Braconidae). We also showed that some of the farmscaping plants increase the lifespan and body nutrient levels of *M. croceipes.* The field studies showed trends indicating that the farmscaping does affect the populations of various insects. We found higher populations of most insects on the farmscaping plants but found no significant decrease of the number of pests on the adjacent tomatoes.

Table of Contents

List of Tables

List of Figures

CHAPTER 1:

INTRODUCTION AND RESEARCH OBJECTIVES

Organic Tomato Farming

Organic farming is the practice of cultivating crops without the use of synthetic pesticides, fertilizers, or growth regulators (Diver et al., 1995). This is practiced to reduce the health risks to humans from ingesting toxic chemicals as well as to reduce the negative impacts of farming on the environment. Organic production was worth $28 billion in 2004 worldwide (Zehnder et al., 2007). Organic products accounted for just under $17 billion in sales in 2008 with an annual market growth of about a 20% per year since 1990 in the U.S. (Rawson, 2008). The amount of certified organic farmland doubled by 2002, and doubled again by 2005. (http://www.ers.usda.gov/Data/Organic). Most organic farming in the United States occurs in the North and West, especially California. In 2005, almost 95% of organic tomato acreage in the U.S. was in California. Also in 2005, Alabama had no certified organic tomato farms (http://www.ers.usda.gov/Data/Organic). The South as a whole has far less organic farming, largely due to the long and hot summer climate that contributes to an abundance of plant diseases and pests. Much of the organic farming in the South is done in the fall and the spring in an attempt to avoid summer pests. Alabama is near the bottom in nearly every type of organic farming (http://www.ers.usda.gov/Data/Organic).

Farmscaping

Organic farmers have to use alternative methods to control pest outbreaks. Farmscaping is a whole-farm, ecological approach to pest management. It can involve the use of hedgerows, insectary plants, covercrops, and water reservoirs to attract and support populations of beneficial organisms (Dufour, 2000). Planting wildflowers or some other form of flowering plants is a common method of farmscaping that can help restore some of the insect diversity which can help keep pest insect populations from growing to damaging levels. Studies have shown that planting flowering plants as farmscaping along field margins increases the biodiversity of the area, which increases predation on pests (Berndt et al., 2002; Jeanneret et al. 2003; Pfiffner and Wyss, 2004; Pfiffner et al., 2003). Pfiffner and Wyss (2004) recommended that 10% of land used in agriculture should be used as ecological compensation area to restore the biodiversity that is lost when a field of one or a few crops is planted. These wildflower strips also provide cover and overwintering habitat for many beneficial insects. Wildflower strips create an artificial habitat for species that would otherwise have to find habitat far from the fields.

Pests of tomatoes

Tomatoes attract a wide variety of pests. Farmers have a very low tolerance for pests on tomatoes because consumers will not buy damaged or blemished fruit. This makes growing tomatoes organically in Alabama especially difficult. The pests of tomatoes can be direct or indirect pests. Common indirect pests include thrips (Thysanoptera), aphids (Hemiptera: Aphididae), and whiteflies (Hemiptera: Aleyrodidae). These insects cause little direct damage to the plant by their feeding. They cause the most damage by vectoring various plant diseases. Lepidopteran larvae are the most common direct pests of tomatoes. Several species of herbivorous true bugs (Hemiptera, suborder Heteroptera) can be direct pests as well.

Indirect pests of tomato

Some of the most serious pests of tomatoes in Alabama are thrips. These tiny insects cause very little direct damage to the plant. However, they are vectors for the tomato spotted wilt virus (TSWV) which causes wilting of the plants and discoloration of the fruit, making it unmarketable. The most common pest thrips are the flower thrips (*Frankliniella* spp.). Thrips adults are tiny (0.5 – 5 mm), elongate, yellow, brown, or black insects. Thrips have unique rasping-sucking mouthparts that have the right mandible either vestigial or completely lacking. Their wings, when present, are long and narrow, with few or no veins, and bordered with a fringe of long hairs. They have an unusual metamorphosis, somewhat intermediate between simple and complete. The first two instars are called larvae and are wingless. The third instar is called the propupa and the fourth instar is called the pupa. In most economically important thrips species, the third and forth instars have external wings but are inactive and do not feed (Triplehorn and Johnson 2005). Most adult thrips feed on plant material, although some are predacious. They are generalists, feeding on a wide variety of plants. Thrips will often find a crop while moving from weeds or surrounding vegetation (Morse and Hoddle, 2006).

Thrips cause their most severe damage by acting as vectors of TSWV which causes the plant to become stunted and eventually die. Early symptoms occur when the terminal leaves stop growing and become distorted (Sikora, 1998). Eventually necrotic spots develop on the leaves and stem. Brownish streaks usually form on the stem.

Infected fruit develop ring spots of discoloration. Infected fruit is still edible but is not marketable due to the discoloration (Sikora, 1998).

Aphids (Hemiptera: Aphididae) are small soft-bodied insects that often are found in clusters on plants. The most common species of aphids on tomatoes are the cotton aphid (*Aphis gossypii* Glover), green peach aphid (*Myzus persicae* (Sulzer)), and the potato aphid (*Macrosiphum euphorbiae* (Thomas)). Aphids have a pear-shaped body with fairly long antennae and a pair of rod-like extensions called cornicles on the posterior end of the abdomen. They have piercing-sucking mouthparts that they use to feed on the internal fluids of the plant. Throughout the growing season aphids reproduce by parthenogenesis, a process where females give birth to females without mating with a male. When populations get too large, they will produce some winged individuals which will migrate to find new host plants. Late in the season, both males and females are produced. They mate and the females produce eggs which overwinter. This reproductive potential causes aphids to become problems quickly because a single individual can produce an entire population quickly. Aphids secrete waste as honeydew which can encourage the growth of sooty mold that can damage plants by blocking photosynthesis (Triplehorn and Johnson 2005). Aphids are usually minor pests of tomatoes in Alabama (Sikora and Zehnder, 2000).

Whiteflies (Hemiptera: Alyrodidae) are tiny white insects with four roughly equal sized wings covered with a waxy powder. They have piercing-sucking mouthparts that they use to feed on the internal fluids of the plants. The first instar nymph is active but the later instars are sessile and look somewhat like scale insects. The last instar is called the pupa. Whiteflies secrete honeydew waste which can lead to the growth of sooty mold.

Sooty mold damages plants by blocking photosynthesis. Whiteflies are minor pests of tomatoes in Alabama (Sikora and Zehnder, 2000).

Direct pests of tomato

Lepidopteran pests are the most common direct pests of tomatoes. Many species of caterpillars are known to attack tomato plants. These include tomato fruitworm *Helocoverpa zea* (Boddie) (Noctuidae), hornworms *Manduca* spp. (Sphingidae), and several species of armyworms *Spodoptera* spp. (Noctuidae). Often caterpillars will feed directly on the fruit, causing it to become unmarketable. Many of these caterpillars are attacked by various species of parasitoid wasps (Hymenoptera). Some true bugs, particularly stink bugs (Hemiptera: Pentatomidae), sometimes feed on the fruits. Their feeding can cause blemishes and make the fruit unmarketable (Sikora and Zehnder, 2000).

Pest Management in Organic Crop Production Systems

Controlling insects and other pests on crops is a problem that humans have had to deal with for as long as they have farmed. The growing of large quantities of a single crop causes a decrease in the biodiversity of both plants and insects in an area. Most of the previous ecosystem is removed to allow for the planting of the desired crop. Monoculture cropping systems provide abundant habitat for a few insect species. These species typically become pests because they have abundant resources and little competition or predation. Pesticides have been the traditional remedy for this situation; however, organic farmers are not able to use many effective traditional insecticides. Many pesticides affect a broad range of arthropods, killing both beneficials and pests (Hagler and Naranjo, 2005). Many pest species have developed resistance to formerly effective pesticides while many natural enemies are susceptible (Edwards et al., 2008). This forces farmers to use increasing amounts of insecticide to achieve the control before resistance. The resulting increase can cause non-target effects on natural enemies and the environment (Bellinger, 1996). The resistant pests have an abundant food supply with few predators which allows them to multiply into abnormally large numbers that then can cause significant damage to the crops.

Beneficial Arthropods

A wide variety of arthropods are beneficial to farmers. These include parasitoid wasps, carabid beetles, spiders, and predatory hemipterans (Jeanneret et. al., 2003). Populations of these arthropods can be influenced by the creation of artificial habitats near agricultural areas. However, different species of beneficial arthropods have very different needs from their habitats. It is very difficult to put all of the needs of these different types of arthropods into one artificial habitat. Flowers are close to being common ground for these arthropods. Many beneficial insects can either feed on the flowers or on other animals attracted to the flowers. The farmscaping plants also provide cover and egg laying sites.

Parasitoid wasps are some of the most effective beneficial arthropods to farmers. Most species are specialists, making them effective control for the species they attack. Populations of certain species of parasitoids can be supplemented with insectary reared wasps. Parasitoids affect pest populations by feeding on the host arthropods as larvae, usually killing the host as the wasp larva completes development. The adults typically live only a few weeks with their reproductive effectiveness somewhat shorter. The adults typically feed only on liquids, usually water or nectar (Lee et.al, 2006). Farmscaping provides a food source close to crops which attracts parasitoids and maintains the population and extends the wasps' effectiveness.

The primary sugar sources in the field for most parasitoids are flowers or hemipteran honeydew. Several species of wasps attack aphids and other hemipterans and will feed on their honeydew. However, a study showed that when given the opportunity, parasitoid wasps chose to feed on nectar from buckwheat flowers planted adjacent to a field of soybeans. In this study, more than 70% of wasps sampled had fed on buckwheat nectar while less than 30% had fed on honeydew from soybean aphids. The researchers were not able to find a correlation between feeding preference and effectiveness in controlling the aphids (Lee et al., 2006).

Flowering strips, mulching, and intercropping are ways to provide good overwintering habitat for many insects and spiders. This diversification of the ecosystem can supplement existing natural biological control by supporting populations of existing natural enemies. Natural enemies of pests can overwinter in large numbers on a field border. When they emerge in spring they find an abundant food source in the pests on the nearby crop (Lemke and Poehling, 2002).

Benefits of Flowering Plants

Studies have shown that certain flowering plants do attract beneficial insects (Nichols et al., 2000; Geiger et al., 2005; Jones and Gillett, 2005). One study tested the effect of sunflowers planted along field borders on organic farms (Jones and Gillett, 2005). The authors reported that plots with sunflowers had significantly more beneficials than crops with no sunflowers. Additionally, significantly more beneficials were found on the crops nearest to the sunflowers than on crops more than 10m away (Jones and

Gillett, 2005). Buckwheat has also been shown to be a common food source for some parasitoids (Burndt et al., 2002). The study could not determine whether feeding on buckwheat nectar increased the lifespan or effectiveness of the parasitoids (Lee et al., 2006).

Several factors must be considered in choosing the plants to be used in farmscaping. The plants must have long blooming periods. The blooming period for farmscaping can be extended by using a mixture of plants that will have some species blooming throughout the growing season for the crop. A seed mixture can cause problems if larger plants such as sunflowers crowd out smaller plants. This can be avoided if the plants are grown in adjacent plots rather than in a uniform mixture. The plants used in farmscaping must not interfere with the health of the crop. It is important to have plants that will not become weeds.

The main objectives of this study were to:

1) Evaluate the effectiveness of several flowering plants as farmscaping plants in organic tomato production by determining their effects on the population levels of both pest and beneficial arthropods.
2) Determine the ability of a parasitoid wasp, *Microplitis croceipes* (Hymenoptera: Braconidae), to feed on floral nectar from the farmscaping plants and whether nectar feeding will enhance the parasitoid's longevity.

CHAPTER 2:

THE EFFECTS OF FARMSCAPING FLOWERING PLANTS ON THE ABUNDANCE AND DIVERSITY OF HERBIVOROUS AND BENEFICIAL INSECTS IN ORGANIC TOMATO FIELDS IN ALABAMA

Introduction

Modern farming is typically done in a monoculture system where the available fields are planted with large amounts of the desired crop. This results in removing the naturally occurring diverse habitat and replacing it with large amounts of a greatly simplified habitat. This change removes resources for most of the organisms in the ecosystem while providing abundant resources for a few organisms (Dufour, 2000). This forces natural enemies to disperse farther from the crop to find food sources (Pfiffner et.al, 2003). The few organisms that can utilize the resources of the crop have limited competition, allowing their populations to quickly grow to the point where they can cause significant economic damage to the desired crop.

Traditionally, farmers have controlled their pest populations with synthetic insecticides. While synthetic insecticides can be effective, they can also cause damage to the environment by affecting non-target organisms and natural enemies in the fields or surrounding ecosystems due to drift or runoff. Repeated and indiscriminate use of insecticides has also resulted in the development of pest resistance (Djihinto et al., 2009; Avilla, C. and J.E. González-Zamora. 2010; Roe et al, 2010). Farmers and scientists have been exploring other methods to make agriculture more sustainable and better for the environment. These include sustainable agriculture and organic farming systems. Organic farming is a system of crop production that does not use synthetic or man-made chemicals or fertilizers.

Organic production of tomatoes (*Solanum lycopersicum* L.) is an emerging industry in Alabama. However, a lack of organically acceptable pest management practices limits the growth and expansion of this industry. Tomatoes are attacked by several key pests in Alabama (Sikora and Zehnder, 2000). These include lepidopteran pests such as the tomato fruitworm (*Helicoverpa zea* (Boddie)), tomato pinworm (*Keiferia lycopersicella* Walsingham), cabbage looper (*Trichoplusia ni* (Hubner)), hornworms (*Manduca* spp.), and some armyworm species (*Spodoptera* spp.). Other key pests include aphids (e.g. green peach aphid, *Myzus persicae* (Sulzer) and potato aphid, *Macrosiphum euphorbiae* (Thomas)), whiteflies (*Bemisia* spp.), plant bugs (Miridae), stink bugs (Pentatomidae), many species of beetles (Coleoptera), and thrips (Thysanoptera) (Sikora and Zehnder, 2000). Thrips are considered by growers to be one of the most serious pests of tomatoes in Alabama because they act as vectors for tomato spotted wilt virus (TSWV), a very destructive disease of tomatoes (Funderburk et.al, 2004, Sikora and Gazaway, 2009).

Organic vegetable farmers typically rely on methods such as crop rotation, cover crops, and non-synthetic insecticides to manage their pests (Diver, 1999; Dufour, 2000). Biological pest control with natural enemies is also a popular practice among organic farmers because many natural enemies occur in the fields and some are commercially available (Dufour, 2000). Key natural enemies of tomato pests in Alabama include predators such as ladybird beetles (Coccinellidae), assassin bugs (Reduviidae), big-eyed bugs (Geocoridae.), damsel bugs (Nabidae), minute pirate bugs (Anthocoridae), lacewing larvae (Chrysopidae), and syrphid fly larvae (Syrphidae), as well as several species of parasitoid wasps (Hymenoptera) and tachinid flies (Tachinidae) (Dufour, 2000). Natural enemies need shelter and food resources, such as nectar and prey, to survive and reproduce. For example, many species of parasitoid wasps have been shown to live longer when provided nectar, honeydew, or artificial sugar sources (Johanowicz and Mitchell, 2000; Olsen et. al, 2000; Wackers, 2001; Bezemer et. al, 2005). Several tactics can be used to promote the establishment and biological control performance of natural enemies in vegetable fields, including the use of select cover crops and farmscaping (Bianchi and Wackers, 2008; Diver et al., 1999).

Farmscaping is an ecological approach to pest management that usually involves planting hedgerows, insectary or flowering plants, cover crops, and water reservoirs to attract and support populations of beneficial organisms (Dufour, 2000). Certain flowering plants attract beneficial insects and may provide alternative or supplemental food sources for them. For example, a study by Jones and Gillett (2005) reported that plots of various crops, including sweet corn, collards, tomatoes, okra, and watermelon, bordered by sunflower had significantly more beneficial arthropods than control plots. Farmscaping can also provide a refuge for natural enemies and habitat for them to complete their life cycle, as well as help maintain the overall biological diversity of the land. However, some weeds and flowering plants can also attract pests or harbor diseases. For example, bull nettle and other weedy nightshade plants are known to harbor pests such as flea beetles and some diseases (Diver et al, 1995). Weedy nightshades, jimsonweed, and plantain also harbor tobacco mosaic virus which is a common viral disease in tomato (Diver et al., 1995). An ideal farmscaping system will attract and maintain populations of natural enemies around the crop without attracting many pests. Potential farmscaping plants identified for vegetable fields include buckwheat, most legumes, as well as members of the umbelliferae (carrot), compositae (sunflower), and lamiaceae (mint) families (Diver et. al, 1995; Dufour, 2000; Berndt et. al, 2002). However, the suitability of these flowering plants as farmscaping plants in organic vegetable production has not been evaluated in Alabama and most other southern states. A study in North Carolina evaluated the effects of planting several commercially available flowering plant seed mixtures advertised to attract beneficial insects. The author found increased amounts of beneficial insects in the flowering plants but could find little effect on the pest populations. This may be caused by the flowering plants being too resource rich, so that the natural enemies do not need to enter the nearby crop (Forehand, 2004).

The objective of this study was to evaluate the effects of planting four species of flowering plants as farmscaping plants immediately adjacent to a crop of organically managed tomatoes on the abundance and diversity of arthropods in and around the crop, specifically the key pests and natural enemies of tomatoes. The ultimate goal of this project was to identify a farmscaping system that will attract natural enemies and enhance the biological control of key tomato pests.

Materials and Methods

Experimental design

This field study was conducted during 2008 and 2009 at two locations in Alabama: E. V. Smith Agricultural Research Station, Shorter, Alabama (E.V.Smith), and North Alabama Horticultural Research Station, Cullman, Alabama (Cullman). Sunflower (*Helianthus annuus* L.) sweet alyssum (*Lobularia maritima* (L.)), buckwheat (*Fagopyrum sagittatum* Moench), dill (*Anethum graveolens* L.), and licorice mint (*Agastache foeniculum* (Pursh)) were evaluated as farmscaping plants using a randomized complete block design (RCBD).

In 2008, the study at E.V. Smith was replicated in three plots of tomatoes (variety: Amelia, used throughout study) separated by a 3m buffer planted with grass. Each tomato plot consisted of five 11m long rows of tomatoes. The two length-wise borders of each plot were divided into five 1 x 1m subplots separated by a 1m grass buffer (Figure 1A). Each of the five farmscaping plant species listed above was planted in a subplot in a randomly determined fashion. The three control plots were located approximately 30m away from the farmscaping plots and had the same dimensions as the farmscaping plots (Figure 1A). The essential difference is that farmscaping plants were not planted on the borders of the control plots. Grasses (primarily cereal rye) were allowed to grow naturally on the borders of the control plants. A similar experimental design was used at the Cullman location but plots were smaller due to limited availability of space at this site. The tomato plots at Cullman consisted of three 5m long rows of tomatoes bordered by farmscaping plants on each side. The plots were separated by a 3m grass buffer. The farmscaping plants were planted in 3, 1m subplots in a randomized order on either side of the tomato plots. The five species of farmscaping plants were planted immediately adjacent to each other without a buffer (Figure 1B). The five farmscaping subplots at

Cullman were treated as one subplot and were not analyzed separately. The samples were taken from different sections of the subplot each time. The three control plots were located approximately 30m away from the farmscaping plots and had the same dimensions as the farmscaping plots but with no farmscaping on the borders.

In 2009, only four of the farmscaping plant species were evaluated at both locations using a RCBD; dill was not evaluated due to poor establishment of this species in 2008. At both locations, four 10 x 10m plots of tomatoes were established. The plots were separated by a 10m grass buffer. Each plot was bordered on each of the four sides by a subplot of a farmscaping plant species. Each farmscaping plant species was planted in a 10 x 1m strip along one side of the tomato plot (Figure 2). Four control plots were located approximately 30m away from the farmscaping plots and had the same dimensions as the farmscaping plots but with no farmscaping on the borders. The tomatoes (*Solanum lycopersicum* L.) were planted on white plastic with drip irrigation. The variety Amelia, a TSWV resistant variety, was used.

Buckwheat and sunflower were directly seeded in the appropriate subplots at the field sites. Sweet alyssum and licorice mint were first grown in the greenhouses at the Plant Science Research Center at Auburn University in February in styrofoam seeding trays and 10cm square plastic pots and transplanted into their appropriate subplots in the field in May. The farmscaping plants were irrigated with a small sprinkler system at E.V. Smith, and with drip irrigation was at Cullman. Weeds were removed by hand.

Data Collection and Analysis

Insect abundance was evaluated with yellow sticky traps (Pherocon AM, Trécé Incorporated, Adair, OK) and by visual sampling in the field. The yellow sticky traps were placed at the center of each farmscaping subplot and tomato plot as well as on the edge of control plots. The traps were attached to stakes at approximately 30 to 100cm high. The sticky traps were collected after being in the field for approximately one week in 2008 and 3 to 5 days in 2009. The traps were then brought back to the lab where the insects collected on the traps were identified. Insect specimens were identified at least to insect order, but usually to family. The data from 2008 were taken on two dates (August 11 and 19, 2008) at E.V. Smith and three dates (August 6, 14, and 22, 2008) at Cullman. In 2009, data were collected on two sampling dates (June 29 and July 24, 2009) at E.V. Smith and on three sampling dates (July 8, 13, and 28, 2009) at Cullman.

Insect trap catch data were combined into major groups such as thrips, aphids, and other hemipteran herbivores (excluding aphids), and parasitoids. Trap data were divided by the number of days the trap was in the field to calculate the average number of insects caught in the trap per day. Trap data were first checked for normality, and if necessary were log transformed (log + 1) , and analyzed with analysis of variance (ANOVA) followed by the Tukey HSD test to test for significant differences among the treatments ($P < 0.05$, JMPIN version 7.0.1, SAS Institute 2007). In all cases, comparisons were made among traps placed in each of the 4-5 farmscaping plants species evaluated versus traps placed in tomatoes bordered by farmscaping (referred to here as farmscaped tomatoes), control tomatoes, and the edge of control plots (the area approximately three feet from the border of the tomato plot where farmscaping is planted in the test plots).

Results

The key insects collected in this study were grouped into four main categories, thrips, aphids, other hemipteran herbivores, and parasitoids. The key families of other hemipteran herbivores identified in this study include Aleyrodidae, Cicadellidae, Cercopidae, Psyllidae, Membracidae, Miridae, Tingidae, and Pentatomidae. These groups accounted for most of the economically important insects collected on the traps. In general, higher numbers of insects were recorded on the farmscaping plants than on the adjacent tomatoes. The results are presented below by year and location.

2008

Unless otherwise stated, the distributions in the 2008 data were normal so no transformations were necessary.

E.V. Smith Research Center:

Thrips: No significant differences were observed among the treatments in the trap captures of thrips on August 11, 2008 ($F = 1.277$, $df = 6$, $P = 0.312$). However, significant differences were observed among the treatments in the trap captures of thrips on August 19, 2008 ($F = 9.450$, $df = 7$, $P = 0.002$). (Figure 3A). Control tomatoes had significantly greater numbers of thrips than buckwheat, licorice mint, sunflower, sweet alyssum, and the edge of control plots. Similarly, tomatoes bordered by farmscaping had significantly greater numbers of thrips than buckwheat, licorice mint, sunflower, and sweet alyssum (Figure 3A).

Aphids: Significant differences were observed among the treatments in the number of aphids trapped on August 11, 2008 ($F = 10.825$, $df = 6$, $P < 0.0001$). Dill, sweet alyssum, and tomatoes bordered by farmscaping had significantly higher numbers of aphids than licorice mint, sunflower, and control tomatoes. Buckwheat also had significantly higher numbers of aphids than sunflower (Figure 3B). Significant differences in aphid trap captures were also recorded among the treatments on August 19, 2008 ($F = 6.582$, $df = 7$, $P = 0.006$). Tomatoes bordered by farmscaping had significantly higher numbers of aphids than buckwheat, sunflower, licorice mint, and control tomatoes. The edge of control plots had significantly higher numbers of aphids than licorice mint (Figure 3B).

Other Hemipteran Herbivores: The data for other hemipteran herbivores on August 11, 2008, was log transformed because it was not normally distributed. No significant differences were observed among other hemipteran herbivores on the traps collected on August 11 ($F = 1.021$, $df = 6$, $P = 0.441$) (Figure 3C). However, trap data collected on August 19, 2008, showed significant differences among the treatments in the number of other hemipteran herbivores ($F = 4.558$, $df = 7$, $P = 0.020$). Sweet alyssum and dill had significantly higher numbers of other hemipteran herbivores than sunflower (Figure 3C).

Parasitoids: The data for parasitoids on August 11, 2008, was log transformed because it was not normally distributed. Significant differences were observed among the treatments on this date ($F = 7.270$, $df = 6$, $P = 0.0003$). Sunflower had significantly higher numbers of parasitoids than sweet alyssum, buckwheat, dill, licorice mint, tomatoes bordered by farmscaping, and control tomatoes (Figure 3D). The data for parasitoids on August 19, 2008, showed no significant differences among the treatments ($F = 0.763$, $df = 7$, $P = 0.631$) (Figure 3D).

Cullman Research Center:

As mentioned in the previous section, because the farmscaping plant species were planted immediately adjacent to each other with no buffer between them at Cullman in 2008, the five farmscaping subplots were treated as one treatment (farmscaping plants), resulting in a total of four treatment comparisons (farmscaping plants, farmscaped tomatoes, control tomatoes, and edge of control plots). However, traps collected from edge of control plots on August 6, 2008, were missing, so only three treatments were compared on this sampling date.

Thrips: Significant differences were observed among the treatments in the number of thrips trapped on August 6, 2008 ($F = 26.259$, $df = 2$, $P < 0.0001$). Thrips were significantly more abundant on control tomatoes than on tomatoes bordered by farmscaping and on the farmscaping treatment (Figure 4A). The data for thrips on August 14, 2008, was log transformed because it was not normally distributed, and subsequent analysis by ANOVA showed significant differences among the treatments ($F = 15.114$, $df = 3$, $P = 0.0003$). Tomatoes bordered by farmscaping and control tomatoes had significantly higher numbers of thrips than the farmscaping treatment and the edge of control plots (Figure 4A). Significant differences were also recorded in the number of thrips on August 22, 2008 ($F = 14.588$, $df = 3$, $P = 0.001$). Control tomatoes had significantly more thrips than all the other treatments (Figure 4A).

Aphids: The data for aphids on August 6, 2008 was log transformed because it was not normally distributed. No significant differences were observed in the number of aphids among the treatments ($F = 1.546$, $df = 2$, $P = 0.245$) (Figure 4B). However, significant differences were recorded among the treatments on August 14, 2008 ($F = 8.788$, $df = 3$, $P = 0.003$). The edge of control plots had significantly higher numbers of aphids than control tomatoes (Figure 4B). No significant differences in aphid trap captures were observed among the treatments on August 22, 2008 ($F = 0.036$, $df = 3$, $P = 0.990$) (Figure 4B).

Other Hemipteran Herbivores: No significant differences among the treatments were observed in the numbers of other hemipteran herbivores on August 6, 2008 ($F = 0.627$, $df = 2$, $P = 0.548$), August 14, 2008 ($F = 1.267$, $df = 3$, $P = 0.333$), and August 22, 2008 ($F = 2.609$, $df = 3$, $P = 0.124$) (Figure 4C).

Parasitoids: Significant differences in the trap captures of parasitoids were observed among the treatments on August 6, 2008 ($F = 7.249$, $df = 2$, $P = 0.006$). The farmscaping treatment had significantly higher numbers of parasitoids than tomatoes bordered by farmscaping (Figure 4D). Significant differences in parasitoid trap captures were also observed among the treatments on August 14, 2008 ($F = 31.882$, $df = 3$, $P < 0.0001$). Control tomatoes had significantly higher numbers of parasitoids than the other treatments. Also, significantly higher numbers of parasitoids were trapped in the farmscaping treatment and tomatoes bordered by farmscaping than in the edge of control plots (Figure 4D). No significant differences in the number of parasitoids were observed on August 22, 2008 ($F = 3.551$, $df = 3$, $P = 0.067$) (Figure 4D).

<u>2009</u>

Traps were left in the field in 2009 for three days before being collected. The numbers of insects on the traps were then divided by the number of days they were in the field to calculate the number of insects per trap per day. Data collected at both locations in 2009 were not normally distributed, so the data were log-transformed prior to analysis.

E.V. Smith Research Center

Trap data were collected on two sampling dates at E.V. Smith in 2009 (June 29 and July 24). Table 1 presents a listing of the main groups of insects collected at this location in 2009.

Thrips: Trap data collected on June 29, 2009, showed significant differences among the treatments in the number of thrips per day (F = 4.337, df = 6, P = 0.005). Significantly higher numbers of thrips were recorded on buckwheat than on control tomatoes or the edge of control plots. Licorice mint had significantly higher numbers of thrips than the edge of control plots (Fig. 5A). Number of thrips per day was also numerically higher on tomatoes bordered by farmscaping compared to control tomatoes; however, this difference was not significant. No significant differences in thrips' numbers were recorded among the treatments on July 24, 2009 (F = 0.551, df = 6, P = 0.764) (Figure 5A). .

Aphids: Trap data collected on June 29, 2009, showed no significant differences among the treatments in the number of aphids per day (F = 1.717, df = 6, P = 0.166). However, significant differences were recorded among the treatments in the number of aphids per day on July 24, 2009 (F = 7.259, df = 6, P = 0.0003). Sweet alyssum had significantly higher numbers of aphids than sunflower and buckwheat. Control tomatoes, tomatoes bordered by farmscaping, and the edge of control plots had significantly more aphids than sunflower. Slightly higher numbers of aphids were recorded in control tomatoes than in tomatoes bordered by farmscaping, but the difference was not significant (Figure 5B).

Other Hemipteran Herbivores: Trap data collected on June 29, 2009, showed significant differences among the treatments in the number of other hemipteran herbivores per day ($F = 6.997$, $df = 6$, $P = 0.0003$). Licorice mint and sweet alyssum had significantly higher numbers of other hemipteran herbivores than tomatoes bordered by farmscaping, control tomatoes, or the edge of control plots. Buckwheat had significantly more other hemipteran herbivores than control tomatoes. Tomatoes bordered by farmscaping had higher number of other hemipteran herbivores than control tomatoes, although this difference was not significant (Figure 5C).

Trap data collected on July 24, 2009, showed significant differences among the treatments in the number of other hemipteran herbivores per day ($F = 15.464$, $df = 6$, $P < 0.0001$). Sweet alyssum had significantly higher numbers of other hemipteran herbivores than buckwheat, tomatoes bordered by farmscaping, control tomatoes, and the edge of control plots. Also, licorice mint, sunflower, and buckwheat had significantly higher numbers of other hemipteran herbivores than tomatoes bordered by farmscaping and the edge of control plots. (Figure 5C).

Parasitoids: Trap data collected on June 29, 2009, showed significant differences among the treatments in the number of parasitoids per day ($F = 6.329$, $df = 6$, $P = 0.0006$). Licorice mint, sunflower, buckwheat, and sweet alyssum all had significantly higher numbers of parasitoids than the edge of control plots. The data also showed numerically higher numbers of parasitoids in tomatoes bordered by farmscaping than in control tomatoes, but the difference was not significant (Figure 5D).

Trap data collected on July 24, 2009, also showed significant differences among the treatments in the number of parasitoids per day ($F = 19.548$, $df = 6$, $P < 0.0001$). Sunflower had significantly higher numbers of parasitoids than buckwheat, tomatoes bordered by farmscaping, control tomatoes, and the edge of control plots. Sweet alyssum and licorice mint also had significantly higher numbers than tomatoes bordered by farmscaping, control tomatoes, and the edge of control plots. Buckwheat had significantly higher numbers of parasitoids than the edge of control plots. Tomatoes bordered by farmscaping had numerically higher numbers of parasitoids than control tomatoes (Figure 5D).

Cullman Research Center

Trap data were collected on three sampling dates at Cullman in 2009 (July 8, 13, and 28). Table 2 presents a listing of the main groups of insects collected at this location.

Thrips: Trap data collected on July 8, 2009, showed significant differences among the treatments in the number of thrips per day ($F = 14.650$, $df = 6$, $P < 0.0001$). Tomatoes bordered by farmscaping and control tomatoes had significantly higher numbers of thrips than licorice mint, sunflower, and the edge of control plots. Licorice mint, buckwheat, sweet alyssum, and the edge of control plots had significantly higher numbers of thrips than sunflower. Control tomatoes had numerically higher numbers of thrips than tomatoes bordered by farmscaping, although the difference was not significant (Figure 6A).

Trap data collected on July 13, 2009, showed significant differences among the treatments in the number of thrips per day ($F = 13.622$, $df = 6$, $P < 0.0001$) Control tomatoes had significantly higher number of thrips than licorice mint, buckwheat, and sunflower. Also, licorice mint, buckwheat, sweet alyssum, tomatoes bordered by farmscaping, and the edge of control plots had significantly higher numbers of thrips than sunflower. Control tomatoes had higher numbers of thrips than tomatoes bordered by farmscaping but the difference was not statistically significant (Figure 6A). Trap data collected on July 28, 2009, showed no significant differences among the treatments in the number of thrips per day ($F = 2.364$, $df = 6$, $P = 0.0667$). (Figure 6A).

Aphids: Trap data collected on July 8, 2009, showed significant differences among the treatments in the number of aphids per day ($F = 11.893$ $df = 6$, $P < 0.0001$). The edge of control plots had significantly higher numbers of aphids than sunflower, buckwheat, tomatoes bordered by farmscaping, and control tomatoes. Licorice mint and sweet alyssum had significantly higher numbers of aphids than sunflower. Tomatoes bordered by farmscaping had slightly higher numbers of aphids than control tomatoes, although the differences were not statistically significant (Figure 6B).

Trap data collected on July 13, 2009, showed significant differences among the treatments in the number of aphids per day ($F = 12.439$, $df = 6$, $P < 0.0001$) The edge of control plots had significantly higher numbers of aphids than buckwheat, sunflower, tomatoes bordered by farmscaping, and control tomatoes. Licorice mint had significantly higher numbers of aphids than buckwheat, sunflower, and tomatoes with farmscaping. Sweet alyssum had significantly higher numbers of aphids than sunflower. Control tomatoes had more aphids than tomatoes bordered by farmscaping but the difference was not statistically significant (Figure 6B).

Trap data collected on July 28, 2009, showed significant differences among the treatments in the number of aphids per day ($F = 16.357$, $df = 6$, $P < 0.0001$). Control tomatoes and the edge of control plots had significantly higher numbers of aphids than licorice mint, buckwheat, and sunflower. Tomatoes bordered by farmscaping had significantly higher numbers of aphids than buckwheat and sunflower. Sweet alyssum and licorice mint had significantly higher numbers of aphids than sunflower. Control tomatoes had numerically higher numbers of aphids than tomatoes with farmscaping but the difference was not significant (Figure 6B).

Other Hemipteran Herbivores: Data collected on July 8, 2009, showed significant differences among the treatments in the number of other hemipteran herbivores per day ($F = 9.899$, $df = 6$, $P < 0.0001$). Licorice mint and sweet alyssum had significantly higher numbers of other hemipteran herbivores than tomatoes bordered by farmscaping, control tomatoes, and the edge of control plots. Sunflower had significantly higher numbers of other hemipteran herbivores than control tomatoes and the edge of control plots. Buckwheat had significantly higher numbers of other hemipteran herbivores than control tomatoes. Tomatoes bordered by farmscaping had numerically higher numbers of other hemipteran herbivores than control tomatoes but the difference was not statistically significant (Figure 6C).

Trap data collected on July 13, 2009, showed significant differences among the treatments in the number of other hemipteran herbivores per day ($F = 9.505$, $df = 6$, $P < 0.0001$). Licorice mint and sweet alyssum had significantly higher numbers of other hemipteran herbivores than sunflower, tomatoes bordered by farmscaping, control tomatoes, and the edge of control plots. Tomatoes bordered by farmscaping had higher number of other hemipteran herbivores than control tomatoes but the difference was not significant (Figure 6C).

Trap data collected on July 28, 2009, showed significant differences among the treatments in the number of other hemipteran herbivores per day ($F = 11.193$, $df = 6$, $P < 0.0001$). Sweet alyssum had significantly higher numbers of other hemipteran herbivores than licorice mint, tomatoes bordered by farmscaping, control tomatoes, and the edge of control plots. Also, sunflower, buckwheat, and licorice mint had significantly higher numbers of other hemipteran herbivores than control tomatoes (Figure 6C).

Parasitoids: Trap data showed no significant differences among the treatments in the number of parasitoids per day on July 8, 2009 ($F = 1.155$, $df = 6$, $P = 0.3666$), and on July 13, 2009 ($F = 4.257$, $df = 6$, $P = 0.0059$) (Figure 6D). However, trap data collected on July 28, 2009, showed significant differences among the treatments in the number of parasitoids per day ($F = 2.787$, $df = 6$, $P = 0.0374$). Sweet alyssum had significantly higher numbers of parasitoids than sunflower. (Figure 6D).

Discussion

Our main objective was to see if the farmscaping plant species would enhance populations of beneficial insects and reduce populations of pest insects in organic tomato fields compared to control organic tomato fields with no farmscaping. In this study we found that the farmscaping plants seemed to affect the various insect groups differently. The data were not consistent and varied by sampling date, location, and year. The differences in the data were likely due to the flowering cycles of the plants and the population dynamics of the insects over the summer.

Thrips: Thrips were the most significant pest of tomatoes found in the fields because of their potential to vector tomato spotted wilt virus (TSWV). The virus can be a problem even with low numbers of thrips. An infected thrips may only need to feed on a plant for five minutes in order to transmit the virus (Culbreath et al. 2003). The primary ways TSWV is controlled is by insecticidal sprays, controlling weeds, removing infected plants, and the use of resistant varieties (Sikora, 1998; Sikora and Zehnder, 2000; Culbreath et al. 2003). The data collected from Cullman in 2008 showed significantly fewer thrips on tomatoes bordered by farmscaping than on the control tomatoes on two of the three sampling dates. The same trend was also observed in 2009 at this location, although the differences were not significant. However, this trend was not as evident at E.V. Smith, which may be partly due to inadequate maintenance of plots at this location.

Among the farmscaping plants, sweet alyssum and buckwheat had the highest numbers of thrips, while sunflower most often had the lowest numbers of thrips. Abundance of thrips was lower late in the season at both sites, likely due to senescence of the farmscaping plants. The reduced abundance of thrips late in the season appears to coincide with the observed increase in aphid densities at this time. An interesting future study would be to determine if there is some kind of competition or replacement between aphids and thrips late in the year. However, these results could also simply be that the thrips were less attracted to sticky traps covered with large numbers of aphids. Overall, the farmscaping plants seemed to have little effect on thrips' populations in the tomato plots. It is apparent that farmscaping alone will not provide sufficient control of thrips due to growers' low tolerance for vectors.

Aphids: The damaged caused by aphids is usually not significant. They are known to transmit some plant diseases but none are widespread in Alabama (Sikora and Zehnder, 2000). The 2008 data showed higher numbers of aphids in tomatoes bordered by farmscaping than in control tomatoes on all sampling dates at both locations. This difference was statistically significant on some sampling dates in 2008; however the trend was not evident in 2009. This may be because weed control in the farmscaping subplots was improved in 2009. Among the farmscaping plants, sunflower consistently had the lowest number of aphids on all dates at both sites.

Other Hemipteran Herbivores: This group includes the families Aleyrodidae, Cicadellidae, Cercopidae, Psyllidae, Membracidae, Miridae, Tingidae, and Pentatomidae. These groups are usually not important pests of tomatoes in Alabama. Whiteflies (Aleyrodidae) are vectors of tomato mottle geminivirus, which is a problem in Florida but is seldom found in Alabama (Sikora and Zehnder, 2000). Stinkbugs (Pentatomidae) are rarely major pests in Alabama but can cause direct damage to fruits (Sikora and Zehnder, 2000). None of the other groups are usually considered pest of tomatoes in Alabama, but they could cause damage in certain situations. The 2008 data showed very little differences between the treatments in the numbers of other hemipteran herbivores. In general, other hemipteran herbivores other than aphids were more abundant on the farmscaping plants than on tomatoes in 2009. Sweet alyssum and licorice mint typically had the highest numbers of other hemipteran herbivores. Both farmscaping species grow low to the ground, which provides easier access to many herbivores. The difference in population levels between tomatoes bordered by farmscaping and control tomatoes was small in every sample in 2008, but the tomatoes bordered by farmscaping had higher levels of other hemipteran herbivores than control tomatoes in all samples at Cullman and in one sample at E.V. Smith in 2009. The differences in the numbers of hemipteran herbivores are usually small but the farmscaping plants do not appear to cause any reduction of the numbers of other hemipteran herbivores in the nearby tomatoes.

Parasitoids: Parasitoids were the most common beneficial arthropods collected. The farmscaping plants seemed to have little effect on parasitoid population in 2008, although higher numbers of parasitoids were recorded on sunflower at E.V. Smith. Parasitoid numbers showed very little differences in most samples in 2009. The samples showed small differences in tomatoes bordered by farmscaping than in control tomatoes at both sites. In general, parasitoids were more abundant on farmscaping plants than on tomatoes. Data from both locations also indicate that parasitoids are attracted to farmscaping plants when the plants are flowering, but their populations may decrease as the farmscaping plants decline.

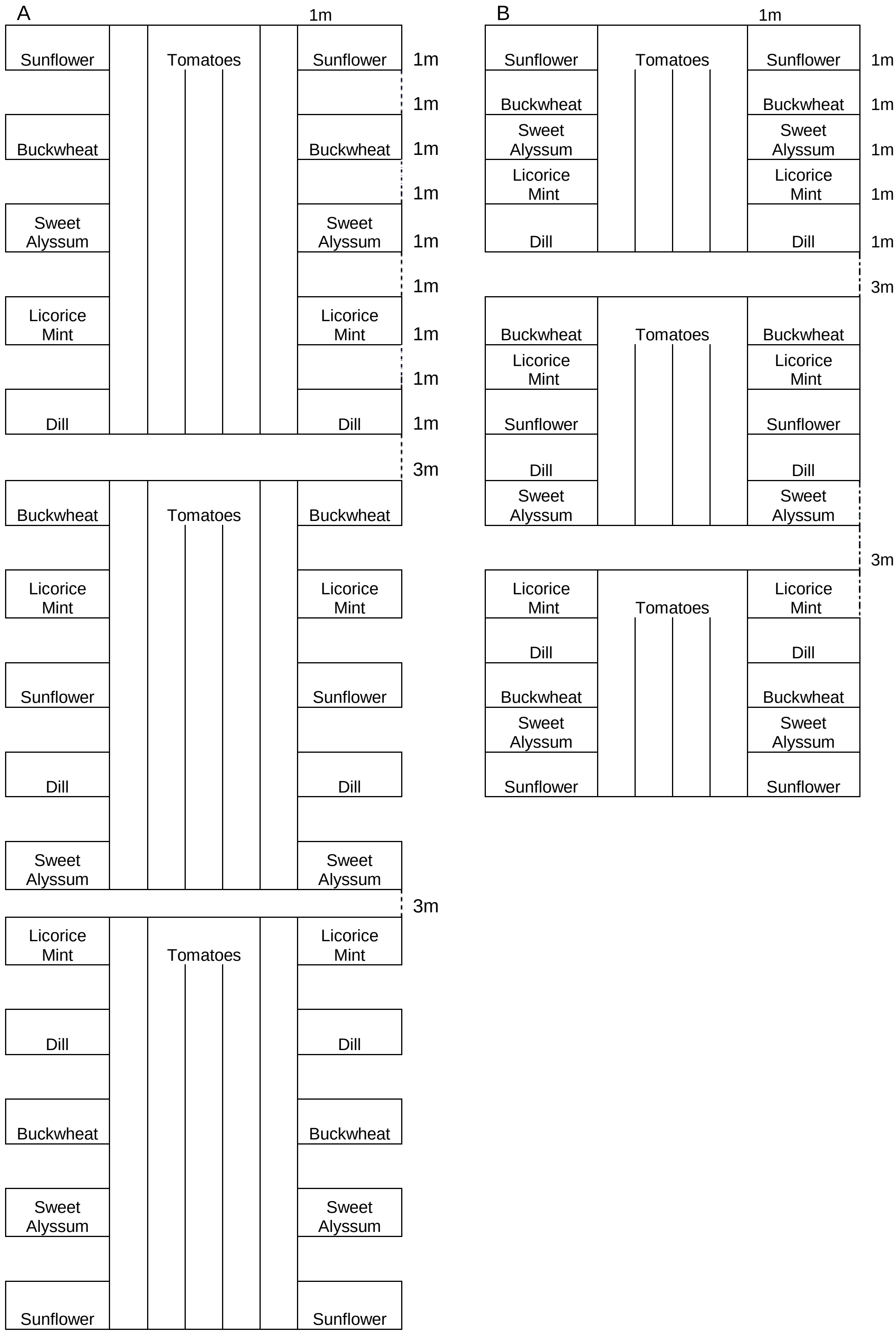
Parasitoid behavior is highly complex and there are several possible reasons why we did not see increased numbers of parasitoids in the tomato plots bordered by farmscaping. Not all species of parasitoids will respond to a treatment in the same way. Pfiffner et al. (2003) found opposite effects of farmscaping on the parasitization rates of different species of Lepidoptera larvae. They found that some Lepidoptera larvae had higher rates of parasitization close to the wildflower border than on the rest of the crop. This result is generally expected. However, one Lepidoptera species had a significantly higher parasitization rate in the crop without wildflower strips than the crop adjacent to the strips. The different sexes of parasitoids may also be reacting differently to the farmscaping. A study by Berndt et al. (2002) found that the planting of buckwheat next to vineyards in New Zealand sometimes increased the numbers of certain parasitoids. In their study they found higher numbers of males on the sticky traps but no significant increase in the number of females. One species had more females collected on the control plots than on the buckwheat. If primarily males were being attracted to the farmscaping in our study, this would explain why there was little change in the number of parasitoids in the tomato because the males would need to search for hosts in the tomatoes.

Lee et al. (2006) found that wasps would feed on nectar from buckwheat plants, but many would then leave the nearby crop and travel to other crops that were farther away. This could provide a possible reason why we did not see much increase in the number of parasitoids in the tomato fields adjacent to farmscaping. The parasitoids may have been using the nectar resources and traveling to other sites to look for hosts.

The greatest difficulty with establishing a viable farmscaping system is maintaining healthy farmscaping plants throughout the growing season. For example buckwheat grows quickly and puts out an attractive flower but the flower may only last for 2 to 3 weeks. Some flowering plants, such as sweet alyssum and licorice mint, have attractive flowers that will last for nearly the entire season. However, they are both very small plants that are easily crowded out by weeds and are difficult to seed. Both plants may require too much time and resources to maintain to make them practical for organic growers. Overall, the most promising farmscaping plant identified in this study is sunflower. In most samples it had among the lowest thrips and aphid populations, as well as some of the highest parasitoid populations. It is also easy to grow and out-competes most weeds. Ideal farmscaping plants should be easy to grow and require little maintenance. They should also not act as a pest reservoir. In this study several farmscaping plants, especially buckwheat and licorice mint (Figure 5A), had fairly high numbers of thrips. These plants may be attracting more thrips than would otherwise occur in the tomato fields.

The main conclusion that can be drawn from this study is that farmscaping alone likely cannot be a solution to a major pest problem in tomatoes in Alabama. Tomato growers have a low tolerance for pests due to demand for unblemished fruit. Farmscaping is particularly difficult to use in Alabama because of the long, hot summers and large amounts of insects. However, farmscaping has potential to be an important part of well managed vegetable fields.

This study also raises several questions that should be explored in future research. What effect do these plants have on tomato insect populations when used alone? Do any of these plants act as pest reservoirs? Could some these plants be used as a trap crop? Is there a competitive effect between populations of aphids and thrips? It would be interesting to repeat this experiment in an environment more suitable for organic vegetable farming.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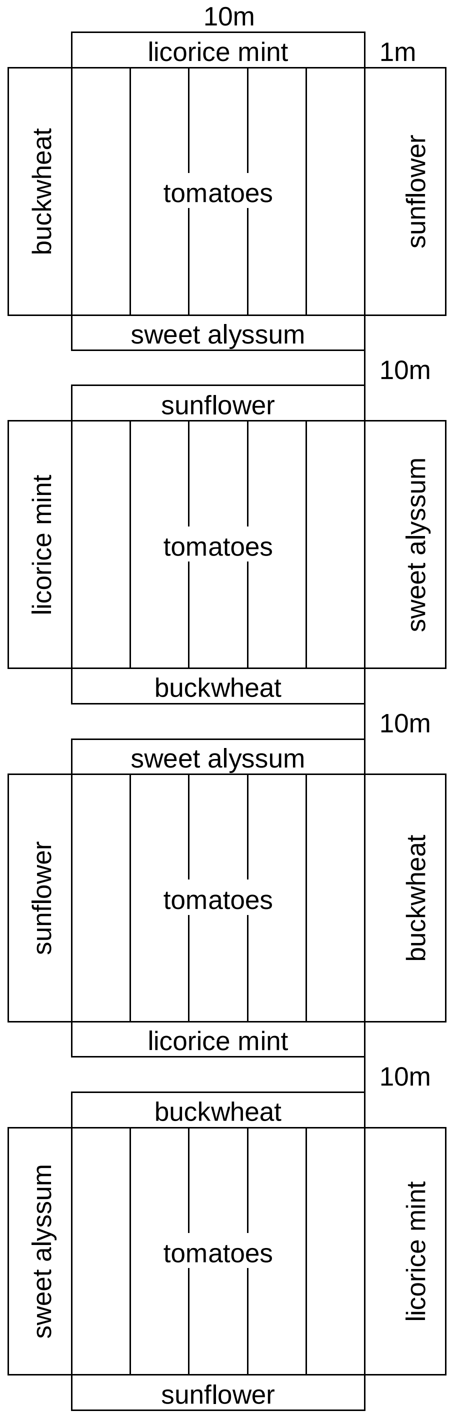

Figure 2. 2009 field test plot layout

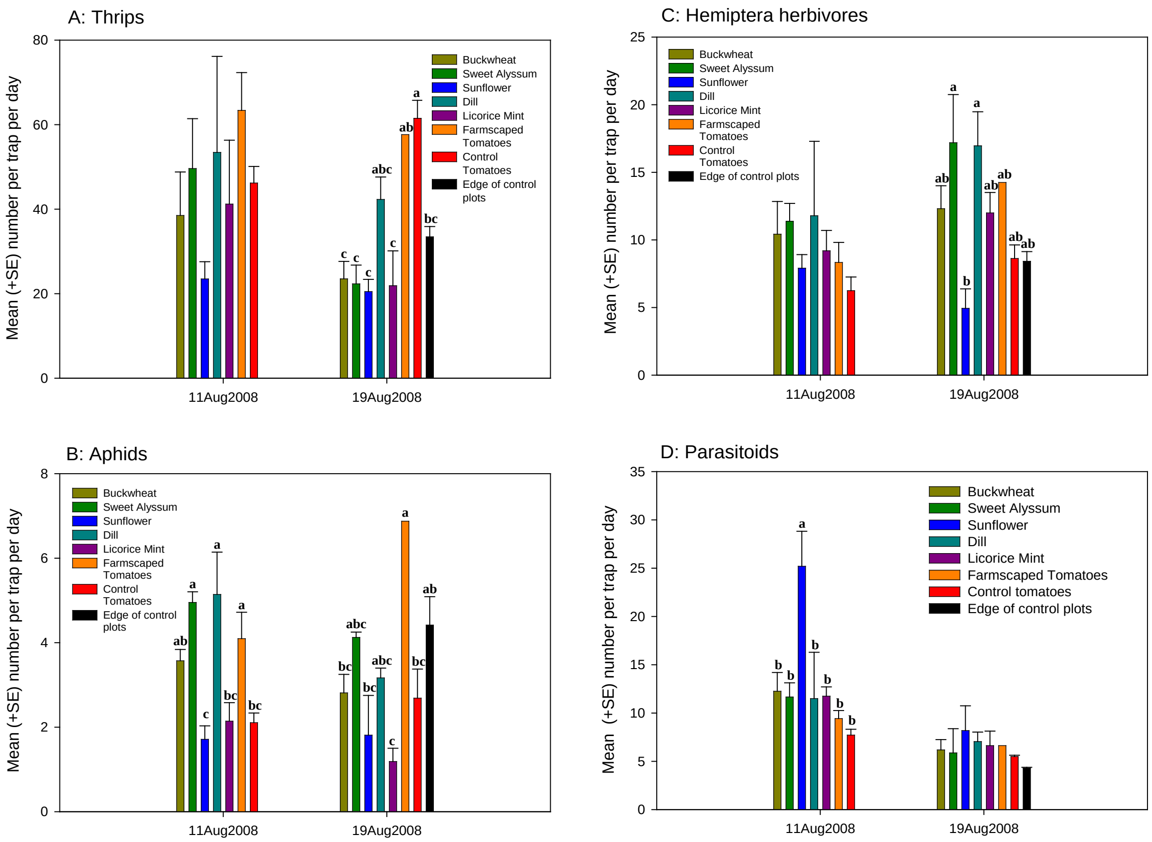

Figure 3. Mean number (+ SE) of key insects collected on sticky traps per day at E.V. Smith in 2008. Means that do not share letters are significantly different.

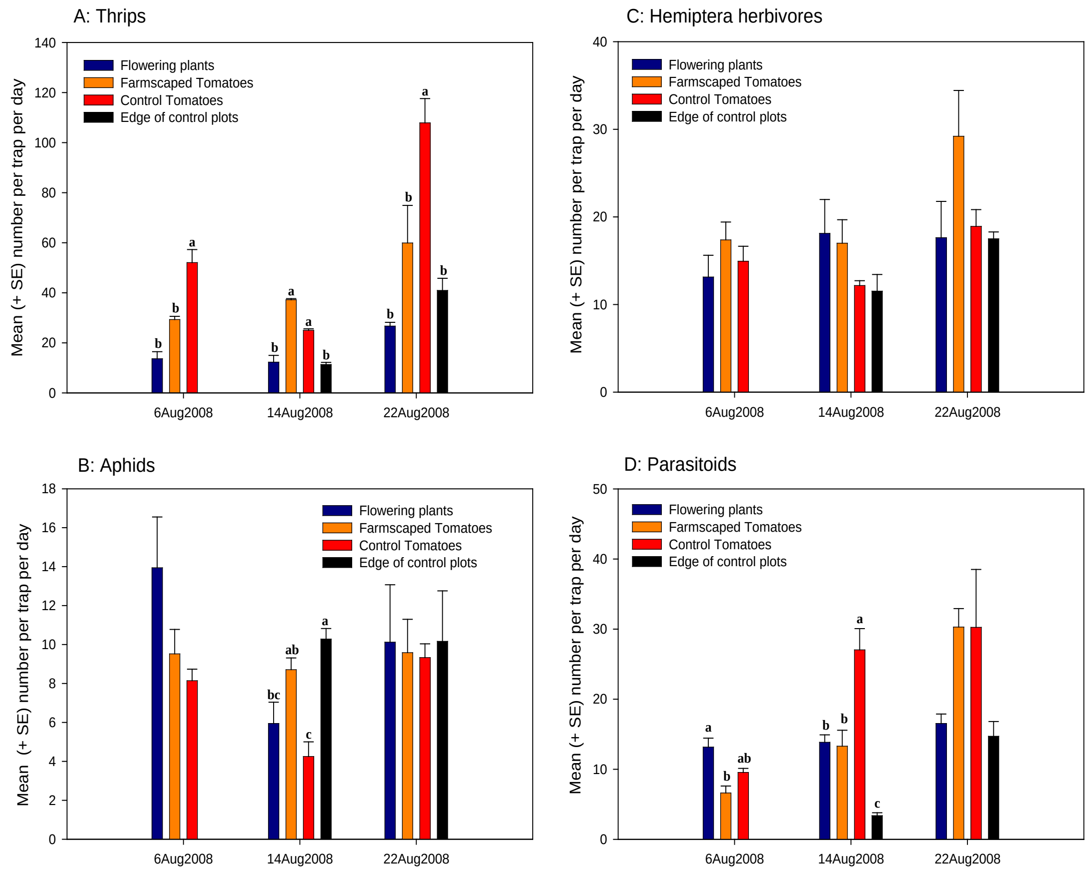

Figure 4. Mean numbers (± SE) of key insects collected on sticky traps per day at Cullman in 2008. Means that do not share letters are significantly different.

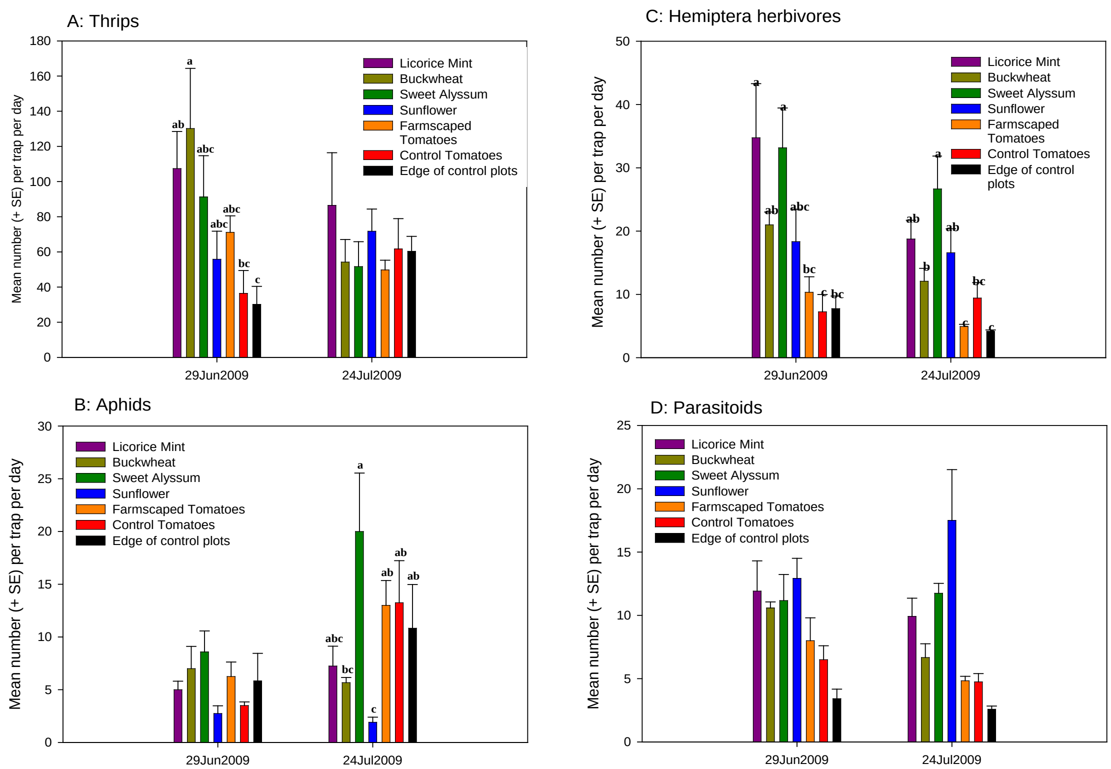

Figure 5. Mean number (± SE) of key insect groups collected on sticky traps per day at E.V.Smith in 2009. Means that do not share letters are significantly different.

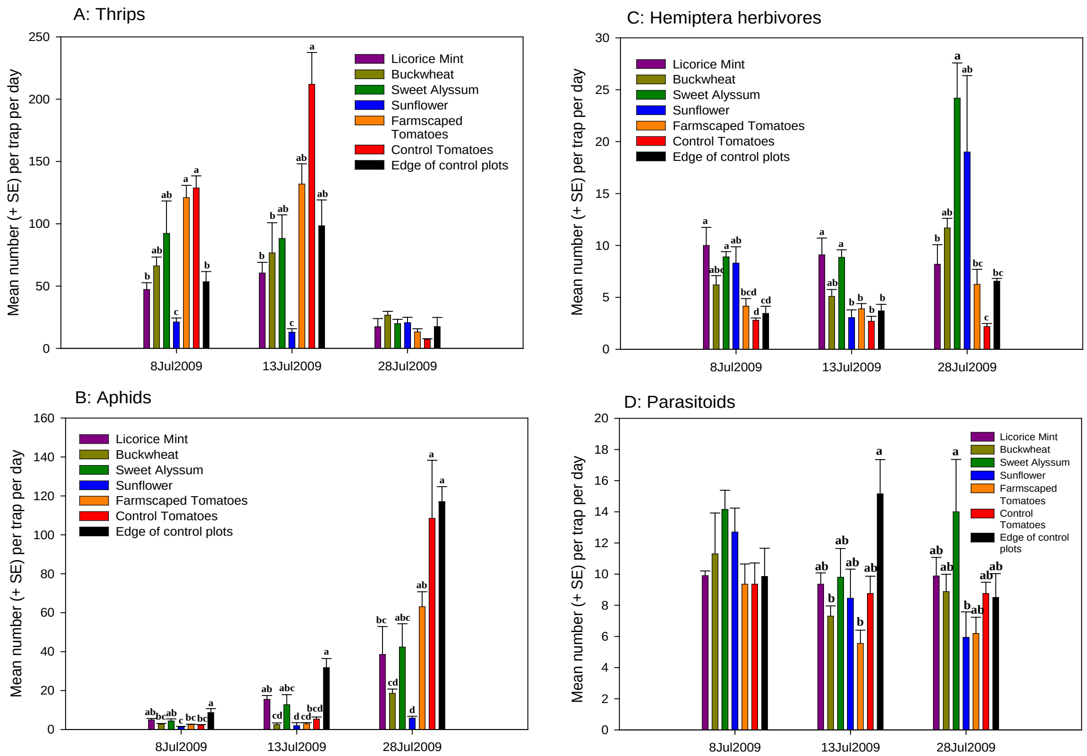

Figure 6. Mean number (+ SE) of key insect groups collected on sticky traps per day at Cullman in 2009. Means that do not share letters are significantly different.

Figure 7. Farmscaping subplot at Cullman Research Station in 2008

Figure 8. Tomato test plot bordered by farmscaping at Cullman Research Station on August 5, 2009

Figure 9: Insects feeding on sunflower at E.V. Smith, July 16, 2009.

Table 1. Groups of insects identified from sticky traps at E.V.Smith.

	Licorice Mint	Buckwheat	Sweet Alyssum	Sunflower	Farmscaped Tomatoes	Control Tomatoes	Control Edge
Acrididae				X			
Alticinae	X	X	X	X	X	X	X
Aleyrodidae	X	X	X	X	X	X	X
Anthicidae		X		X			X
Anthocoridae	X	X	X	X	X	X	X
Aphididae	X	X	X	X	X	X	X
Apidae				X			
Argidae	X	X	X	X	X	X	X
Brachycera	X	X	X	X	X	X	X
Braconidae			X	X		X	
Carabidae	X		X		X	X	X
Cerambycidae	X						
Cercopidae	X	X	X	X	X	X	X
Chrysomelidae		X	X	X	X	X	
Cicadellidae	X	X	X	X	X	X	X
Coccinellidae	X		X	X			X
Curculionidae	X	X	X	X	X	X	X
Cydnidae	X			X	X		
Elateridae		X	X	X	X	X	X
Formicidae	X	X	X	X	X	X	X
Geocoridae		X		X			
Gryllidae	X				X		
Halictidae	X	X	X	X	X	X	X
Hesperiidae	X	X	X	X		X	X
Ichneumonidae			X			X	
Latridiidae	X	X	X	X	X	X	X
Membracidae	X	X	X			X	X
Miridae	X		X	X	X	X	
Mordellidae	X	X	X	X	X	X	X
Mymaridae	X	X	X	X	X	X	X
Nabidae		X					
Nematocera	X	X	X	X	X	X	X
Nymphalidae				X			
Parasitoids	X	X	X	X	X	X	X
Pentatomidae	X						
Pieridae						X	
Psocoptera	X	X	X	X	X	X	X
Psyllidae			X	X			X
Scarabaeidae					X		X
Signiphoridae	X	X	X	X	X	X	X
Tettigoniidae	X	X	X				X
Thrips	X	X	X	X	X	X	X
Tingidae		X					

Table 2. Groups of insects identified from sticky traps at Cullman.

	Licorice Mint	Buckwheat	Sweet Alyssum	Sunflower	Farmscaped Tomatoes	Control Tomatoes	Control edge
Aleyrodidae	X	X	X	X	X	X	X
Alticinae	X	X	X	X	X	X	X
Anthicidae	X	X		X	X	X	X
Anthocoridae	X	X	X	X	X	X	X
Aphididae	X	X	X	X	X	X	X
Apidae	X	X					
Argidae	X	X	X	X	X	X	X
Berytidae							X
Brachycera	X	X	X	X	X	X	X
Carabidae		X	X	X	X	X	X
Cercopidae	X	X	X	X	X	X	X
Chrysomelidae	X	X	X	X	X	X	X
Cicadellidae	X	X	X	X	X	X	X
Coccinellidae	X		X	X			X
Colorado Potato Beetle						X	
Curculionidae	X	X	X	X	X	X	X
Cydnidae	X	X	X	X	X	X	X
Elateridae	X	X	X	X	X	X	X
Formicidae	X	X	X	X	X	X	X
Geocoridae	X	X	X	X	X	X	X
Gryllidae	X			X	X		
Halictidae	X	X	X	X	X	X	X
Latridiidae	X	X	X	X	X	X	X
Membracidae	X	X	X	X	X	X	X
Miridae	X	X	X	X	X		
Mordellidae	X	X	X	X	X	X	X
Adult Lepidoptera		X	X	X	X		
Nabidae					X		
Nematocera	X	X	X	X	X	X	X
Parasitoids	X	X	X	X	X	X	X
Pentatomidae	X	X		X	X	X	
Psocoptera	X	X	X	X	X	X	X
Psyllidae	X	X	X	X	X		X
Scarabaeidae	X		X	X	X	X	X
Tettigoniidae				X			
Thysanoptera	X	X	X	X	X	X	X
Tingidae					X		

CHAPTER 3:

SUITABILITY OF SOME FARMSCAPING PLANTS AS NECTAR SOURCES FOR THE PARASITOID WASP, *MICROPLITIS CROCEIPES:* EFFECTS ON LONGEVITY AND BODY NUTRIENTS

Introduction

Farmscaping is an ecological approach to pest management that usually involves planting hedgerows, insectary, or flowering plants to attract and support populations of beneficial organisms (Dufour, 2000). Farmscaping plants are planted to attract and provide resources to beneficial insects that may not otherwise be available in a monoculture crop field. These resources provided to natural enemies can include shelter, reproductive habitat, and alternative or supplemental food sources (Dufour, 2000; Landis et al., 2000; Lee et al., 2006).

The concept of farmscaping is partly based on the knowledge that natural enemies require supplemental food sources to achieve maximum fitness. For example, adult parasitoid wasps of many species are known to require sugar meals for maximum longevity (Fadamiro and Heimpel, 2001; Wackers, 2001; Hogervorst et al., 2007). Increased longevity may enhance reproduction by allowing parasitoids more time for host location and attack (Heimpel and Jervis, 2005). The positive effect of sugar feeding on longevity and/or fecundity has been demonstrated for many parasitoid species in the laboratory (e.g., Heimpel et al., 1997; Lee et al., 2004; Olson et al., 2000, Fadamiro and Heimpel, 2001, Fadamiro et al. 2005).

Sugar is naturally available to parasitoids in the field primarily in the form of nectar and honeydew (Heimpel et al, 1997; Lee et al., 2004). The current trend involving planting of farmscaping plants in field borders to enhance natural biological control in many agroecosystems is based partly on the demonstrated impact of sugar feeding on the lifespan of various parasitoid species (Heimpel et al., 1997; Olsen et al, 2000; Burndt et al., 2002). However, only very few studies have demonstrated the ability of parasitoids to feed on nectar sources (Lee et al., 2004; Johanowicz and Mitchell, 2000). Since nectar sugars consist primarily of sucrose, and its two monosaccharide components, glucose, and fructose (Wackers, 2001; Lee et al., 2004), nectar should be a good food source for parasitoids. However, the ability of parasitoids to utilize different nectar sources is dependent on several factors including floral morphology, nectar accessibility and parasitoid mouthpart morphology (Jervis, 1998; Johanowicz and Mitchell, 2000). We cannot assume that key species of parasitoids have the ability to utilize various nectar sources. The ability of the desired parasitoid species to feed on the particular plant must first be evaluated prior to recommending the plant species for use in a particular agroecosystem.

We recently undertook a preliminary field study which tested the potential of these plants as farmscaping plants in central Alabama (T. Nafziger and H. Fadamiro, unpublished data). In that study, high numbers of parasitoids were sometimes recorded on some of the farmscaping plants, suggesting that they are attractive to parasitoids. However, it was not clear if the parasitoids could successfully obtain nectar from these plants or if the plants could enhance parasitoid lifespan. The goal of this study was to evaluate the suitability of some potential farmscaping plants as floral nectar sources for *Microplitis croceipes* (Cresson) (Hymenoptera: Braconidae), an important specialist parasitoid of *Helicoverpa* zea (Boddie) (Lepidoptera: Noctuidae) caterpillars and related species in the southern United States (Lewis et al., 1991). *H. zea*, also referred to as tomato fruitworm or cotton bollworm, is a major pest of tomatoes in Alabama and other parts of the United States (Wagner, 2005; Flanders and Smith, 2008). Adult *M. croceipes* is usually provided with artificial sugar solutions during rearing but little is known about its ability to utilize floral nectar as food in the field. The farmscaping plants tested in this study were sweet alyssum (*Lobularia maritima*), buckwheat (*Fagopyrum sagittatum*), and licorice mint (*Agastache foeniculum*). Buckwheat and sweet alyssum were selected based on previous studies which showed their potential as effective farmscaping plants (Stephens et al., 1998; Johanowicz and Mitchell, 2000; Burndt et al., 2002). Licorice mint was selected based on its availability and abundant flowers. We 1) tested the effects of feeding on these flowering plants on the longevity of *M. croceipes* females and males; and 2) determined if *M. croceipes* females have the ability to obtain nutrients from the nectar of the farmscaping plants.

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Methods

Farmscaping plants

Buckwheat, sweet alyssum, and licorice mint were tested for their suitability as nectar sources for *M. croceipes*. The plants were grown at the Auburn University Plant Science Research Center on earthworm castings in 4-inch diameter plastic pots at about

22 ± 5 °C, »65 ± 10% r.h., and a photoperiod of L12:D12. All plants were grown using standard greenhouse practices and were watered two times a day**.** Fresh farmscaping plants were maintained throughout the test period by sowing each species weekly.

Parasitoids

The parent culture of *M. croceipes* was provided by the USDA-ARS, Insect Biology and Population Management Research Laboratory (Tifton, Georgia, USA). *M. croceipes* was reared on caterpillars of *Heliothis virescens* Fab (Lepidoptera: Noctuidae), as described by Lewis and Burton (1970). Eggs purchased from Benzone Research (Carlisle, PA, USA) were used to start laboratory colonies of *H. virescens*, which were reared on a laboratory-prepared pinto bean diet (Shorey and Hale 1965) at 25 ± 1°C, 75 ± 5% relative humidity and 14 h light:10 h dark photoperiod. Newly emerged adult parasitoids were collected daily, sexed, and assigned to the different treatments.

Longevity

The survivorship of adult female and male *Microplitis croceipes* was compared when provided the following five treatments as food: 1) sweet alyssum plant, 2) buckwheat plant, 3) licorice mint plant, 4) honey, and 5) water only. In this and the sugar feeding experiments, honey was used as a positive control (e.g., Johanowicz and Mitchell, 2000), whereas water was the negative control. Newly emerged parasitoids were placed in groups of 6 individuals (3 per sex) in a 30 x 30 x 30 cm screen cage (BugDorm-1, Megaview Science Education Services Co., Ltd., Taichung, Taiwan) and provided with one of the treatments. All treatments were provided with water. The cages were checked daily for survival and dead wasps were removed. The experiment was replicated five times for a total of 15 individuals per sex per treatment. Survivorship data for each sex was analyzed separately by using analysis of variance (ANOVA) followed by the Tukey-Kramer HSD test for multiple comparison of means and significant differences between the sexes were determined for each diet treatment using the Student's t-test ($P < 0.05$, SAS Institute, 2007).

Sugar feeding

Microplitis croceipes females were put in a screen cage (same type used for the longevity tests) and provided with sweet alyssum, buckwheat, licorice mint, honey, or water only. All treatments were provided with water. The wasps were allowed to feed for three days. They were then removed, frozen, and bioassayed to analyze the gut contents. The amount of gut sugars, glycogen, and lipids in the individual wasps was estimated using the procedures described by Olson et al. (2000), Fadamiro and Heimpel (2001), and Fadamiro et al. (2005). An individual wasp was crushed with a plastic pestle in a 1.5mL microcentrifuge tube containing 50 mL of 2% sodium sulphate solution and placed on ice. The dissolved nutrients were then extracted with 450 mL of chloroformmethanol (1:2), after which the tube was vortexed. The tube was then centrifuged at 10,000 *g* for 2 min and 200 mL of the resulting supernatant was transferred to a glass tube (12-mm diameter 75-mm long) for the sugar assays. Another 200 mL was transferred to a similar glass tube for the lipid assay. The precipitate was left in the microcentrifuge tube for the glycogen assay. All tubes were heated at $90^{o}C$ until approximately 50 mL of solution was left in the sugar tube and all solution was evaporated from the lipid and glycogen tubes.

Fructose. To estimate the amount of fructose, 950 mL anthrone reagent was added to the sugar tube, mixed thoroughly and left to react at room temperature for 1.5 h (cold anthrone reading). After the reaction time elapsed, the solution was poured into a 1.5mL methacrylate cuvette and the optical density (absorbance) measured at 625nm using a spectrophotometer. To convert absorbance readings to absolute fructose amounts (mg), standard curves were generated by determining the cold anthrone absorbance (at 625 nm) of different amounts (1–50 mg; three replicates per dose) of pure fructose (Fisher, Fairlawn, New Jersey). A linear regression was the best fit and generated the linear equation: (Fructose (μg) = 72.917*absorbance - 1.506). The total amount of gut sugars (amount of sugars present in the insect crop) in each wasp was estimated by multiplying the fructose amount by five. This was carried out because sucrose (which was fed to the wasps) consists of equal parts of fructose and glucose, and the glucose does not react at room temperature (Fadamiro & Heimpel, 2001). Therefore, the cold anthrone reading must be multiplied by two to give an estimate of total gut sugars. Furthermore, because only 200 mL of the original 500 mL was used for the fructose (cold anthrone) assay, it was necessary to multiply this amount further by 2.5 to estimate the total amount of gut sugars.

Glycogen. One mL of anthrone reagent was added to the microcentrifuge tube containing the precipitate. After centrifugation, the tube was heated at 90 ^{o}C for 10 min and then cooled on ice and the absorbance read at 625 nm. Glycogen standard calibration curves were generated by determining the absorbance of oyster glycogen (ICN Biomedicals, Aurora, Ohio) at a range of 1–50 mg (three replicates per dose). A linear regression was the best fit and generated the linear equation: (Glycogen (μg) =

78.332*absorbance - 2.149). The equation was used to convert absorbance readings to absolute glycogen amount (µg). The amount of glycogen estimated above was considered to be representative of the whole wasp because all glycogen in the sample is presumed to precipitate to the bottom of the tube.

Lipids. The amount of lipids in each wasp was determined by adding 40 mL of sulphuric acid to the tube containing the lipid precipitate. The tube was then heated at 90^{o}C for 2 min, cooled on ice, and 960 mL of a vanillin phosphoric acid reagent was added. The solution in the tube was left to react at room temperature for 30 min, mixed, and the absorbance read at 525 nm. To convert absorbance values to absolute lipid amounts (µg), lipid standard curves were generated by determining the absorbance of pure vegetable oil at a range of 1–50 mg (three replicates per dose). A linear regression was the best fit and generated the linear equation: (Lipids (µg) = 81.010625*Lipid (absorbance) + 1.6917706). This equation was used to convert absorbance readings to absolute lipid amount. To estimate the total amount of lipids present in each wasp, the lipid amount was multiplied by 2.5 because 200 mL of the original 500 mL was used for the assay (Fadamiro et al., 2005). The experiment was replicated ten times per treatment.

Results

Longevity

Diet had a significant effect on the longevity of both female ($F = 23.088$, $df = 4$, $P < 0.0001$) and male ($F = 35.043$, $df = 4$, $P < 0.0001$) *Microplitis croceipes* (Figure 10). Parasitoids were observed to attempt to feed on all three flowers used in this experiment. Female wasps that fed on honey lived significantly longer than any other treatment.

Wasps that fed on buckwheat and licorice mint lived significantly longer than wasps that fed on sweet alyssum or just water. Female wasps that fed on sweet alyssum lived longer than wasps that only fed on water but the difference was not statistically significant (Figure 10A).

Male wasps that fed only on honey lived significantly longer than wasps in any other treatment. Males that fed on buckwheat lived significantly longer than males that had only water. Males that fed on licorice mint and sweet alyssum lived longer than males with just water but the differences were not significant (Figure 10B). Survivorship curves showing longevity of the parasitoids on the different treatments are presented in Figure 11.

Female wasps lived significantly longer than males in the honey ($F = 4.642$, $df = 1$, $P = 0.0403$), licorice mint ($F = 10.993$, $df = 1$, $P = 0.0028$), buckwheat ($F = 7.031$, $df = 1$, $P = 0.0130$), and water ($F = 8.802$, $df = 1$, $P = 0.0062$) treatments and marginally significantly longer in the sweet alyssum treatment ($F = 4.258$, $df = 1$, $P = 0.0500$) (Figure 12).

Sugar feeding

The gut sugar and glycogen data were log transformed because they were not normally distributed.

Gut sugars: Significant differences were found in the amount of gut sugars detected in wasps in the different treatments ($F = 5.670$, $df = 4$, $P = 0.001$). Wasps fed on honey had significantly greater amounts of gut sugars than the wasps that fed on water or licorice mint. Wasps that fed on buckwheat had significantly greater amounts of gut sugar than wasps that fed on licorice mint (Figure 13A).

Glycogen: Significant differences were found in the amounts of glycogen detected in wasps in the different treatments ($F = 8.021$, $df = 4$, $P < 0.0001$). Wasps fed on honey had significantly more glycogen than the wasps that fed on water, licorice mint, or sweet alyssum (Figure 13B).

Lipids: Significant differences were found in the amount of lipids detected in wasps in the different treatments ($F = 5.165$, $df = 4$, $P = 0.002$). Wasps fed on honey had significantly higher lipid levels than wasps that fed on the remaining treatments (Figure 13C).

Discussion

Adult *M. croceipes* were shown to have increased longevity when provided with some of the farmscaping plants. We also determined in this study that they are capable of feeding on some of the farmscaping plants. *M. croceipes* showed slightly higher body nutrient levels when provided with farmscaping plants. In the longevity experiment, both sexes of *M. croceipes* were observed to forage on the farmscaping plants but only buckwheat and licorice mint significantly enhanced their longevity. Females had a significantly longer lifespan than males. Females lived longer than males on virtually all the treatments. This was especially evident in the buckwheat and licorice mint treatments. Similar results showing greater longevity for females than conspecific males have been reported for some other parasitoid species (Olsen et al., 2000). Higher female longevity simply may be because females have more need for nutrients than males in order to provide energy for host location and oviposition.

The results of the feeding studies showed significantly higher carbohydrate nutrient levels in female wasps provided with honey but none of the flowering plants caused a significant increase in body nutrient levels. However, wasps provided with buckwheat had numerically higher body carbohydrate nutrient levels than wasps provided water or the other farmscaping treatments. These results together with the significant increase in wasp longevity confirm the ability of *M. croceipes* to utilize buckwheat nectar. Others have also reported on the ability of several parasitoid species to utilize buckwheat (Stephens et al., 1998; Nicholls et al., 2000; Lee et al., 2004; Fadamiro and Chen, 2005).

Sucrose and its monomer components, glucose and fructose, are the sugars in nectar that have been shown to have the greatest effect on the lifespan of parasitoid wasps (Wackers, 2001). Nectar sugar primarily contains these same components (Wackers, 2001), which may explain the increased longevity recorded with buckwheat nectar in this study. In contrast, very low amounts of gut sugars and glycogen were detected in wasps provided licorice mint, despite our results which showed increased longevity with this farmscaping treatment. The reasons for these somewhat contrasting results are not clear, but it is plausible that the wasps were able to obtain just enough nutrients from licorice mint to enhance their longevity but not enough to remain in their gut or store as glycogen. Alternatively, the wasps may have been able to obtain some non-sugar nutrients, such as pollen or other resources, from licorice mint which may enhance their lifespan and biological fitness. Pollen has been reported to be beneficial to some parasitoids although direct feeding on pollen is likely uncommon (Jervis et al., 1996). Further studies are necessary to determine the basis for the increased longevity obtained with licorice mint. In general, the results of the longevity and feeding tests confirmed the inability of the wasps to utilize sweet alyssum nectar.

Our results on the differential utilization of the farmscaping plants by *M. croceipes* may be explained by several factors, in particular differences in floral morphology and nectar accessibility. Both factors strongly affect parasitoid foraging and ability to obtain nectar nutrients (Patt et al., 1997). The positive results obtained with buckwheat are not surprising because of its relatively accessible nectar. Our observations showed that *M. croceipes* adults foraged on sweet alyssum, but apparently were unable to utilize the nectar. This may indicate that sweet alyssum florets are morphologically incompatible with the mouthparts of *M. croceipes*, as has been suggested for other insect and plant interactions (Patt et al., 1997; Jervis, 1998, Fadamiro and Chen, 2005). However, we believe that it is more likely that sweet alyssum nectar is of inferior quality to *M. croceipes*. Future studies on the nectar composition of the different farmscaping plants would be helpful in determining if the negative results recorded with sweet alyssum in this study are related to inferior nectar quality.

Feeding on buckwheat caused a modest increase in body carbohydrate nutrient levels but did not result in increased lipid levels, suggesting that adult *M. croceipes* are incapable of converting dietary sucrose to lipids, as reported for other parasitoid species (Olson et al., 2000; Fadamiro & Heimpel, 2001; Giron & Casas, 2003; Lee et al., 2004; Fadamiro et al. 2005). However, wasps that fed on honey had significantly higher lipid levels. We did run a basic test for lipids with the honey and discovered that the honey used in the tests contained some lipids as a component (T. Nafziger, unpublished data). This indicates that the increased lipid levels obtained for honey-fed wasps were not due to lipogenic ability of the wasps. In general, the enhancement of longevity of *M. croceipes* by some treatments in this study may suggest a synovigenic (i.e. emergence with some immature eggs) life history strategy for this species, since proovigenic species are typically short-lived and thus have little need for sugar feeding in the field (Jervis et al., 2001; Ellers and Jervis, 2004; Chen et al., 2005; Jervis et al., 2008).

In conclusion, buckwheat and licorice mint were identified in this study as beneficial to *M. croceipes* and may also be suitable to many other key parasitoids of tomato pests. Buckwheat is readily established, requires little maintenance, and flowers for three to four weeks. Licorice mint is relatively more difficult to establish in the field but flowers for nearly two months as long as it is maintained. Sweet alyssum does not grow well in the field and requires extensive maintenance due to its susceptibility to be overgrown with weeds. In our studies, sweet alyssum provided little benefit to *M. croceipes* in either nutritional value or longevity. Ongoing field studies will further evaluate the suitability of the flowering plants as farmscaping plants in Alabama.

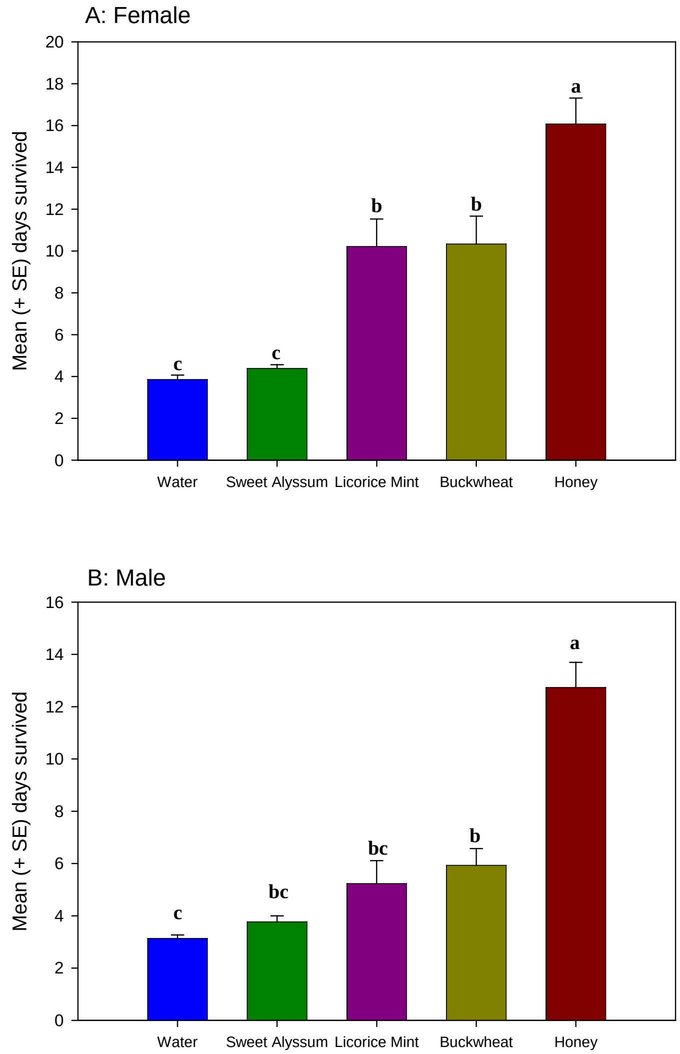

Figure 10. Longevity (mean days ± SE) of female (A) and male (B) *M. croceipes* provided different diet treatments.

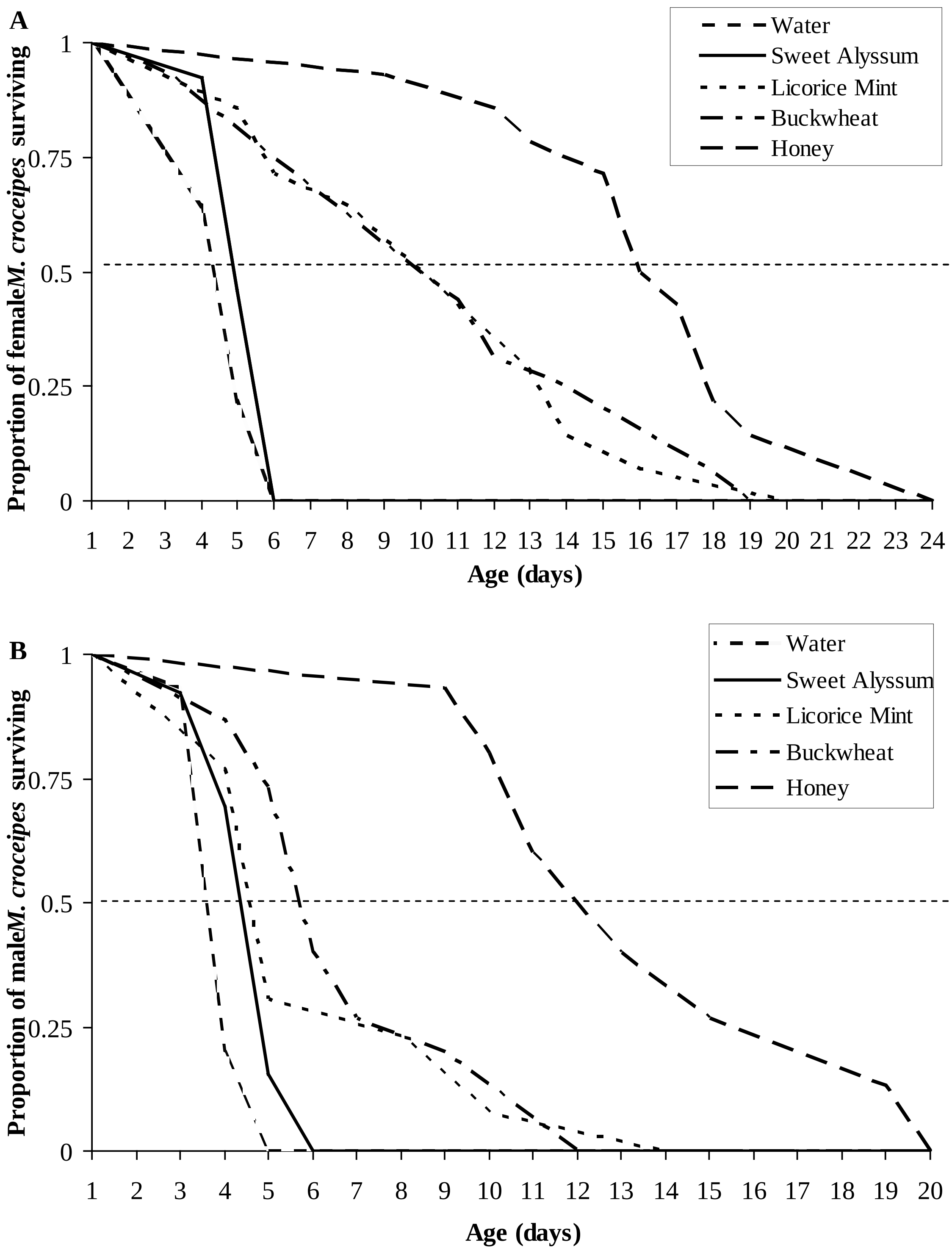

Figure 11. Survivorship curve for female (A) and male (B) *M. crociepes* provided with different diet treatments. Dashed line at 0.5 survivorship indicates median longevity for each treatment.

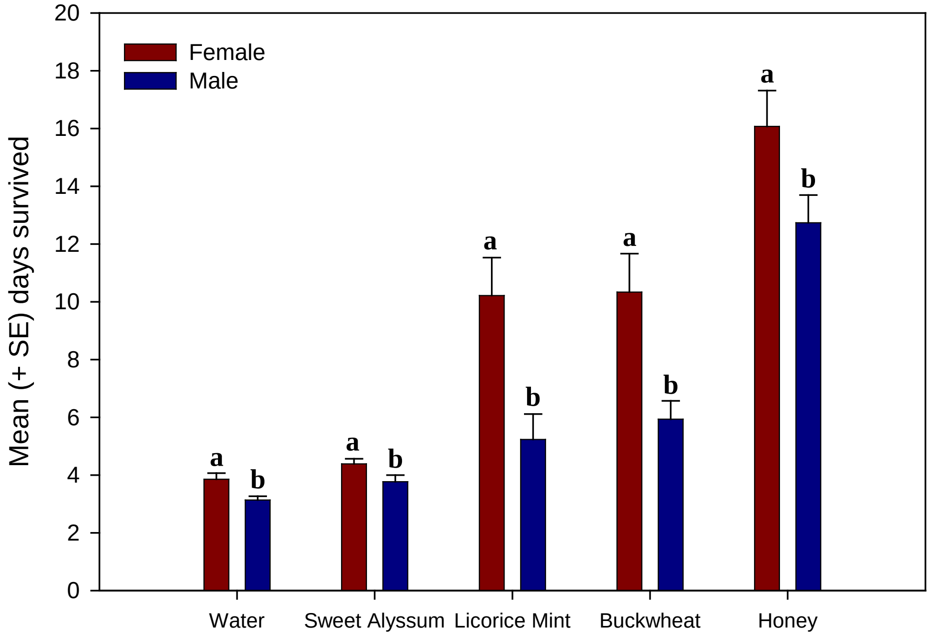

Figure 12: Sexual differences in the longevity (mean days ± SE) of *M. croceipes* on each diet treatment.

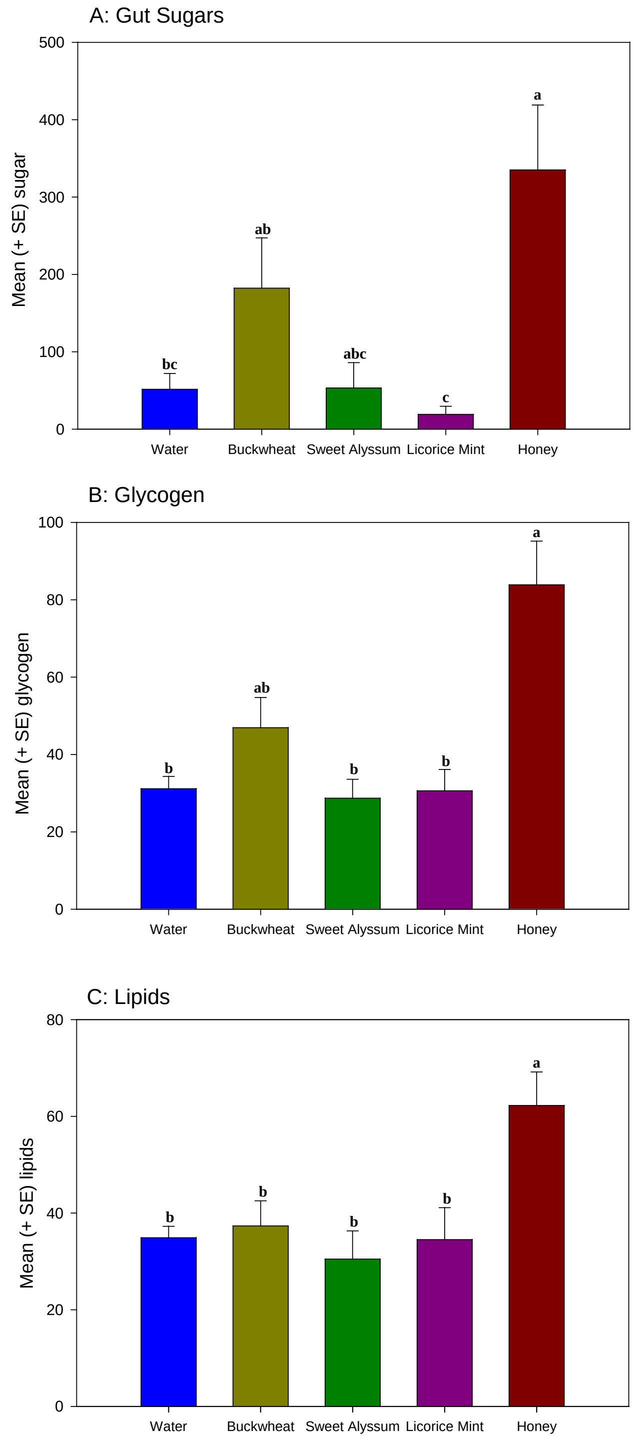

Figure 13: Mean (+ SE) nutrient levels (µg) in female *Microplitis croceipes* provided different diet treatments.

CHAPTER 4:

REFLECTIONS ON THE POTENTIAL OF FARMSCAPING TO ENHANCE PEST MANAGEMENT IN ORGANIC TOMATOES IN ALABAMA

Tomatoes are vulnerable to many pests. Pest populations can reach damaging levels quickly due to the long, warm summers. The hypothesis behind farmscaping is that increasing the diversity of vegetation around the field will lead to a greater diversity of natural enemies that will result in lower pest populations. Farmscaping is not intended to fix an existing pest problem or to cause complete eradication of a pest. Ideally farmscaping should keep pest populations below the economic threshold. The arthropod communities in tomato fields in Alabama are highly complex. Farmscaping cannot be expected to work against all pests in all situations.

The different species, even within the same group (i.e. parasitoids), may react differently to the farmscaping plants. High numbers of beneficials in the farmscaping plants does not necessarily indicate that there will be higher numbers in the crop. The farmscaping plants may be so much more attractive to the beneficials that they do not venture into the crop. These same resources that are included in the field may also be providing additional resources to pests, causing their populations in some situations to increase faster.

The findings in chapter 2 indicate that the farmscaping plants are as attractive to thrips as the tomatoes. This is a serious drawback to using farmscaping plants around tomatoes. As discussed in chapter 2, tomato spotted wilt virus (TSWV) is a serious problem to tomato growers in Alabama. Thrips are the primary vector of TSWV. As with any vector, only a single infected individual can cause a disease outbreak. Growers typically have a very low tolerance for vectors because of this potential of only a few individuals to cause significant damage. Farmscaping will likely not be practical in situations where the primary pest is a disease vector. This issue with thrips will likely keep farmscaping from being an attractive option to organic farmers because of the apparent inability of the farmscaping to significantly lower thrips populations.

Farmscaping does have potential to be useful in some situations. Each potential farmscaping plant should be tested individually to determine what insects it attracts without the effects of other plants in close proximity. Each plant may have different affects on the various species of pests. The types of plants that should be recommended to farmers will likely vary based on the pest problem. Some of these plants that are attractive to pests could potentially be used as trap crops. This may not be the typical way farmscaping plants are expected to work but they could still be effective. These plants may work better in areas where the climate is less conducive to quick pest outbreaks.

Farmscaping may be effective in reducing the numbers of certain pests. The most common beneficials associated with farmscaping are parasitoids. The expected relationship is that the adult parasitoid will be attracted to the farmscaping flowers to obtain a sugar meal. The females will then be close to the pests in the adjacent tomato fields, making finding suitable hosts readily available. There may be some cases where this does work but I have been unable to confirm this in my study. One way farmscaping could be used is to augment a parasitoids species that is known to feed on the farmscaping plant used. This way the specific resources for the natural enemy would be provided, helping it to establish a significant population. A farmscaping technique that even slows the growth of the pest population would be useful to growers.

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