# EVALUATION OF LIVING AND SYNTHETIC MULCHES IN ZUCCHINI FOR CONTROL OF HOMOPTERAN PESTS

By

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Living and synthetic mulches were evaluated for control of the silverleaf whitefly (*Bemisia argentifolii* Bellows and Perring) and aphids in zucchini. Two living mulches, buckwheat (*Fagopyrum esculentum* Moench) and white clover (*Trifolium repens* L.); and two synthetic mulches (reflective and white) were evaluated during fall 2002 and fall 2003. Results from trap and foliar counts showed that reflective and buckwheat mulches consistently had fewer incidences of adult whiteflies and aphids compared with the other mulch treatments evaluated, including bare ground (control).

In 2003, a significant increase in the diversity of natural enemies was seen throughout all treatments. Living mulch treatments had higher natural-enemy populations than did the synthetic mulch and bare-ground treatments. Diversity of natural enemies did not differ in synthetic mulch vs. bare-ground treatments.

The effectiveness of mulches for controlling immature whitefly numbers, and the incidence of squash silverleaf disorder were inconsistent between years. Although

squash silverleaf disorder has been known to reduce yields, it did not appear to be a major factor in this study. Additional data taken at the end of the 2003 season revealed that two viral strains (PRSV-W and WMV-2) were present in the field. However, visual symptoms associated with these viral diseases did not occur until the final weeks of harvest, and thus had little effect on zucchini yield.

Although white mulch consistently had higher adult whitefly and aphid populations than other mulch treatments, there were no significant differences between white and reflective mulch when comparing yield. Overall, synthetic mulches had significantly higher yields than living mulch and bare ground. The deleterious effects of competition from the living mulches on zucchini yield outweighed any positive benefits they may have had on reducing aphid and whitefly pest populations.

# CHAPTER 1
# INTRODUCTION

Cucurbits are a major vegetable crop grown in Florida. During the 2002-03 field season, Florida growers harvested over 45,000 acres of cucurbits valued at over $170 million. Despite these numbers, rising costs associated with preventing insect related problems, combined with cheaper imports from Mexico have threatened the production and value of many Florida cucurbits. Currently, crop-plant physiological disorders and insect-transmitted diseases have become serious problems for many growers around the state.

One of the most important plant physiological disorders in cucurbits is squash silverleaf (SSL) disorder. SSL is associated with the feeding of immature whiteflies (*Bemisia argentifolii* Bellows and Perring) and is characterized by silvering of the adaxial leaf surface and blanching of fruit (Yokomi et al. 1990, Costa et al. 1993, Jimenez et al. 1995). Variations in the feeding densities of immature whiteflies have been shown to affect the severity of SSL symptoms, which can develop in as little as 14 days (Yokomi et al. 1990, Schuster et al. 1991, Costa et al. 1993).

It has been estimated that homopteran pests spread over 90% of insect-borne diseases of plants (Eastop 1977). The most important vectors of plant viruses include the aphids, which have been known to transmit 275 different viral disorders (Nault 1997). Crops in the Cucurbitaceae are highly susceptible to several of these insect-transmitted viruses. Important viruses affecting cucurbits in Florida include zucchini yellow mosaic virus (ZYMV), watermelon mosaic virus-2 (WMV-2), cucumber mosaic virus (CMV), and papaya ringspot virus-watermelon strain (PRSV-W) (Adlerz 1978, Provvidenti et al. 1984, Purcifull et al. 1988). Symptoms of these viruses include pronounced reduction in growth; the occurrence of yellowing, mosaic, and blistering of leaves; and reduced fruit set (Demski and Chalkley 1974, Lisa et al. 1981). In addition, the fruits harvested from infected plants are often malformed and distorted, rendering them unmarketable (Blua and Perring 1989).

Several aphid species have been associated with transmitting these viruses in a stylet-borne non-persistent manner (Coudriet 1962, Lisa et al. 1981, Adlerz 1987, Castle et al. 1992). Stylet-borne viruses are characterized by having no latent period within the vector, and have an infectivity of a few hours or days. This, coupled with the rapid acquisition and inoculation of the virus during brief test probes into the plant epidermis, can allow rapid spread throughout a given area.

In addition to transmitting viruses and causing plant disorders, heavy infestations of whiteflies and aphids generally cause a reduction in plant vigor (Barlow et al. 1977, Buntin et al. 1993). The excretion of honeydew by these insects can serve as an important medium for promoting growth of sooty mold fungi (*Capnodium* spp.), which can further reduce plant vigor and yield (Byrne and Miller 1990, Palumbo et al. 2000). The unpredictability and severity of these cucurbit pests and associated diseases in conjunction with injury from secondary pests makes efficient management strategies necessary in a cucurbit-production system.

Currently, pesticides play a major role in the pest management of cucurbits. However, this control strategy can become problematic. For instance, frequent use of insecticides leads to increased production costs, and increases potential for resistance. In addition, a heightened awareness of the harmful effects of pesticides to non target organisms and the environment have led many to search for alternative methods for pest control. The overall goal of my research was to investigate pest management tactics that would suppress the activity of homopteran pests.

Our hypothesis was that the use of living and synthetic (reflective) mulches would suppress the activity of whiteflies and aphids, thus reducing viral infection and the occurrence of plant disorders. Developing cultural management practices for pest control is an important way to establish ecologically friendly measures to provide growers with sustainable approaches to pest management. Because of the importance of cucurbit sales in Florida (and other areas of the United States and the world) and the limitations of traditional methods for management of homopteran pests, additional management strategies are needed that can serve as stand-alone practices or be used in conjunction with other pest-management approaches.

Cucurbits are generally produced in Florida for spring, early summer, and fall markets. Different varieties can be planted throughout the year, depending on climatic conditions, with production practices varying for each environmental situation. The adaptability and assortment of cucurbits grown in Florida has created a diverse market for growers to compete.

Cucurbits in Florida are grown on raised beds covered with synthetic mulches. Traditionally, farmers have used white, or white on black mulches in the fall; and black in the winter and spring. Reflective and living mulches have also been used in cucurbit production (Hooks et al. 1998, Summers and Stapleton 2002). Soil moisture is maintained through several irrigation practices that can include overhead, drip, seepage, or furrow. Fertilizers are generally incorporated into the bed before mulching, with supplements applied through irrigation tubes or a liquid-fertilizer injection wheel. Management of diseases, weeds, and insects is accomplished by a variety of chemicals. Plant pollination is another important factor in cucurbit production. Many insects can pollinate cucurbit plants, but it is generally recommended that honeybee hives be placed near cucurbit fields. One hive per 2 acres is recommended to facilitate adequate pollination of plants (Maynard et al. 2003).

# CHAPTER 2
# LITERATURE REVIEW

The first step in any IPM program is to understand the biology and behavior of the pest species involved.  Once an understanding of these concepts is developed, efficient methods for monitoring can be established.  The development of pest management tactics requires the collection of repeated systematic data that is unbiased, and gives an adequate picture of the field dynamics.  Without this information, it is uncertain as to which tactic should be incorporated into the program, so that the most effective management practices are attained.

## Silverleaf Whiteflies

The silverleaf whitefly, *Bemisia argentifolii*, occurs in many tropical and subtropical habitats as well as greenhouses.  Research has shown that direct feeding pressure and deposition of honeydew by adult whitefly populations can cause significant damage and economic loss to a variety of cultivars (Van Lenteren and Noldus 1990, Perring et al. 1993).  However, the silverleaf whitefly's potential as a vector for virus, and its ability to induce plant impairments have gained it particular attention (Costa and Brown 1990, Yokomi et al. 1990, Schuster et al. 1991, Polston and Anderson 1997).  One important disorder, squash silverleaf disorder (SSL), is characterized by the silvering of the adaxial leaf surface of cucurbit plants.  This disorder is typically seen in late summer and fall crops, and can cause substantial economic losses to growers.

**Biology and Behavior**

The silverleaf whitefly is primarily polyphagous and colonizes predominantly annual, herbaceous plants (Brown et al. 1995). There are four nymphal instars that characterize whitefly development from egg to pupae. The first nymphal instars are usually referred to as crawlers, and are capable of limited movement while the second, third, and fourth instars are immobile. Completion of all four instars last approximately 17-21 days under optimum conditions. Females are generally larger than males throughout all instars (Tsai and Wang 1996). The nymphal stage of the whitefly life cycle can induce a variety of phytotoxic disorders. In squash, feeding by as few as two to three nymphs per plant can induce SSL disorder (Costa et al. 1993). The silvering of leaves is believed to be a plant response to feeding, and its severity varies directly with the number of feeding immatures (Yokomi et al. 1990, Schuster et al. 1991, Costa et al. 1993, Jimenez et al. 1993). Air spaces between the epidermis and palisade cells of leaves cause the characteristic silvered color. This change in color, chlorophyll content, and light reflectance reduces the photosynthetic ability of the plant species (Burger et al. 1988, Jimenez et al. 1995). It has been estimated that photosynthesis can be reduced by up to 30% in severe cases (Burger et al. 1988, Cardoza et al. 2000).

After development through the nymphal and pupal stages, adult whiteflies emerge. Movement of adults for feeding and oviposition occur on the shaded abaxial surface of suitable host leaves (Simmons 1994). Females live between 10 to 24 days, and can lay anywhere from 66 to 300 eggs (Tsai and Wang 1996). They prefer to oviposite on young leaves, which creates a stratification of different life stages as the host crop plant grows (Gould and Naranjo 1999). Similarly, factors such as leaf shape, color, and nitrogen content can also affect ovipositional preference (Mound 1962, Butler et al. 1986, Bentz et al. 1995). Although wind is the main mechanism for dispersal over long and short distances, unintentional transport by people can occur (Blackmer and Byrne 1993, Brown et al. 1995).

**Monitoring**

Immature whiteflies spend a prominent amount of their time in an immobile feeding stage. Monitoring for immatures has involved removal of disks from selected leaves. These leaf disks are then examined under a microscope for identification of nymphal stages and/or species (Hook et al. 1998, Gould and Naranjo 1999).

Whitefly adults respond strongly to visual cues in their environment. For instance, adult whiteflies have a strong attraction to wavelengths of light falling in the yellow spectra of the visible color range (Mound 1962). Yellow sticky traps have been used effectively in many crop systems for monitoring whiteflies. In addition to monitoring via traps, in-situ counts may also be an efficient way to track whitefly distribution between selected plots.

## Aphids

Aphids can be found on a variety of host plants throughout the world. Their ability to transmit numerous plant viruses coupled with their high reproductive rates have qualified them as an important pest in agricultural systems. Although feeding by aphids can reduce plant vigor and yield (Barlow et al. 1977, Breen and Teetes 1986), the non-persistent transmission of stylet-borne viruses is a more significant problem to growers worldwide. Additionally, viruses are typically transmitted by transient alate species creating further management difficulties (Broadbent et al. 1950, Swenson 1968). Other factors, such as their small size and highly polymorphic nature, can make identification of problematic aphid species difficult.

**Biology and Behavior**

The life cycle of many aphid species can become rather complex. Variations in hosts, reproduction, biology, and activity can occur within the annual cycle of a single species (Kring 1959). Aphids can typically be grouped as monoecious (nonhost-alternating), or heteroecious (host alternating). Monoecious species require only one or a few related host plant species while heteroecious species generally require two or more different species of plants in separate families to complete their lifecycle.

Reproduction is accomplished through sexual (holocyclic) and/or parthenogenetic (anholocyclic) forms. In warm climates, sexual forms tend not to be as important as in colder regions (Miyazaki 1987). Females that reproduce parthenogenetically are viviparous, and can produce a new generation in as little as a week. With a short reproductive and developmental time, numerous generations are possible within one production season.

Dispersal is accomplished by alate or winged morphs while apterous or wingless aphids typically remain restricted to the plant surface. During flight, alate aphids respond strongly to visual stimuli and locate potential host plants by contrasting the soil background with plant foliage (Kring 1972, Liburd et al. 1998). Aphids determine host suitability after landing and making brief, shallow test probes with their stylets on potential host plants. If the plant is not suitable, the aphid will move to another potential host repeating the process. This behavior is especially important since transmission of stylet-borne viruses can occur from these test probes before aphid management is implemented (Nault 1997).

Aphids do not have chemosensory organs on the labium or tips of the mandibular or maxillary stylets. Ingestion of plant fluids to the precibarium where chemosensilla are located is required for host recognition. If the ingested fluids do not induce phagostimulation, extravasation of fluids back through the precibarium and maxillary food canal occurs. It is within the maxillary food canal where it is believed that the main attachment of these potyviruses, the most important group of aphid-transmitted viruses, occurs and where transmission to hosts can take place (Nault 1997). Additionally, these viruses can reach epidemic proportions as a result of secondary spread.

### Monitoring

Aphids generally respond to two different wavelengths of light. Once alate aphids have finished development of wings, they become strongly attracted to shortwave or ultraviolet light. This attraction induces the aphid to fly toward the sky in either a high level migratory flight, which can last from one to several hours, or a low level non-migratory flight over short distances (Kring 1972). Since a correlation can generally be seen between the number of alate aphids trapped and the percentage of virus infection for a particular crop (Zitter and Simons 1980), water pan-traps have been used as an effective monitoring tool (Heathcote 1957, Adlerz 1987). Pan-traps allow for an efficient means to track aphid activity within a particular field.

High wavelengths of light, such as yellow and green, tend to stimulate alighting and settling behavior (Kring 1967, Webb et al. 1994). In general, plants that show obvious yellowing symptoms will have the greater aphid populations (Zitter and Simons 1980). For this reason, in-situ counts can be an effective way to monitor the population dynamics that can exist between plants within a given area.

## Management of Whiteflies and Aphids

Complications in management can arise from a combination of factors involved in the reproductive rates of whitefly and aphid species. These factors can include food quality, host plant species, natural enemies, and temperature. Although many of these factors are uncontrollable by growers, food quality can be regulated to some extent by the application of fertilizer and/or other chemicals. Augmentative releases of certain natural enemies can also be accomplished with some degree of efficiency.

Economic losses via virus or plant disorders have forced growers to use seedlings crossprotected with mild virus strains for resistance (Cho et al. 1992). However, the highly variable nature of these virus strains (Lisa and Lecoq 1984) and the fact that homopteran pests can injure plants in several ways (Jackson et. al 2000) makes the success of using cross-protection uncertain in infected areas. Furthermore, cucurbit plantings may be prone to attack by several viral diseases within the same planting period, making it difficult to develop varieties that are resistant to all of these strains (Purcifull et al. 1988). Another problem is that plants developed to be physically resistant to a specific insect pest may also have a detrimental impact on its associated parasitoid by disrupting their searching behavior or entrapping them (Gruenhagen and Perring 1999), subsequently reducing natural control of insect pests.

**Synthetic Mulch**

Synthetic mulches (i.e., polyethylene films) are an efficient means for reducing many crop pests (Costa et al. 1994, Csizinszky et al. 1997, Smith et al. 2000). In general, they regulate soil temperature and can increase the speed of above ground plant growth (Schalk et al. 1979, Decoteau et al. 1989), while also affecting the flight pattern and behavior of insect pest species (Zitter and Simons 1980, Costa and Robb 1999). This ability to attract or repel insects can be important in reducing the incidence and severity of pest species and any associated diseases. Utilization of reflective mulches resulted in marked decreases in whitefly (Csizinszky et al. 1995) and aphid (Alderz and Everett

1968, Wolfenbarger and Moore 1968) populations, and has been used as an alternative to conventional pesticides and white or black synthetic mulches. Other color mulches such as yellow and red have attracted aphids and whiteflies, respectively, in the past (Wolfenbarger and Moore 1968, Csizinszky et al. 1995). However, disposal of synthetic mulches following crop termination can be problematic and may interfere with routine farming practices such as cultivation. Additionally, a reduction in the effectiveness in synthetic mulches can occur as the area of foliage increases throughout the growing season. One alternative to synthetic mulch is the use of water-soluble biodegradable silver spray mulch (Liburd et al. 1998). However, weathering, dust, and soil accumulation can decrease the effectiveness and make biodegradable mulches more attractive to aphids (Summers et al. 1995).

**Living Mulch**

Living mulch (diversified crops) increases diversity and the overall sustainability of many cropping systems. They are cover crops grown within a marketable cash crop to reduce erosion, enhance fertility, improve soil quality, and suppress weeds while also reducing the incidence and severity of pest insects. Root (1973) suggested two hypotheses as to why herbivore loads are reduced in these diverse crop habitats. The resource concentration hypothesis predicts that herbivores will more readily find, reproduce, and remain in monoculture environments of their host plants because resources are more localized and habitable within these areas. His other hypothesis theorized that predators and parasitoids are more effective in floristically diverse ecosystems because of the availability of greater and more diverse food resources and refuge.

Living mulches can also be thought of as a "protection crop" if planted within or around a crop field. These companion crops can provide additional feeding sites for potential infectious insects, reducing the spread of non-persistent viruses and disorders throughout the cash crop. Toba et al. (1977) demonstrated that a "protection crop" of wheat, *Triticum aestivum*, delayed the frequency and severity of aphid transmitted non-persistent viruses in cantaloupe. In a similar study, Bernays (1999) showed that the whitefly, *Bemisia tabaci* Gennadius, spent less time on plants exposed to environments containing multiple plant species. These whiteflies also demonstrated greater levels of restlessness compared to whiteflies in monoculture environments, which led Bernays to suggest that whitefly movement within field situations could be limited in homogenous environments.

Several studies using living mulch have shown that fewer whiteflies (Hooks et al. 1998), aphids (Smith 1969, Kloen and Altieri 1990, Costello and Altieri 1995, Hooks et al. 1998), and occurrences of insect transmitted diseases (Power 1987, Hussein and Samad 1993, Hooks et al. 1998) occur in habitats with diversified crops compared with monoculture crops. Hooks et al. (1998) planted zucchini (*Cucurbita pepo*) between rows containing buckwheat (*Fagopyrum esculentum*) and yellow mustard (*Sinapsis alba*), and found that densities of *A. gossypii* and *B. argentifolii* and the conveyance of aphid-transmitted diseases and SSL disorder on zucchini were reduced in these living mulch treatments when compared to monoculture plantings.

**Impact on Yield**

Despite the effectiveness of standard white mulch for production practices, studies conducted by Adlerz and Everett (1968) have shown that white polyethylene can increase the number of aphids trapped when compared to bare ground. This can have negative impacts to future yield if the pressures of aphid-borne viruses are high within a field. In addition, the loss in efficiency of synthetic mulches due to weathering and plant concealment have led some to look at alternative mulching systems for cucurbits (Hooks et al. 1998). Unfortunately, the potential gain in pest suppression by living mulches may be offset by delayed development and yield reduction from competition between the crop and mulch (Andow 1986).

It is my primary goal to make valid comparisons between living and synthetic mulching systems. By focusing attention on what works more effectively, we can develop new strategies for pest management suppression, which will increase yields, lower production costs, and further our understanding of the rationale behind these pest responses. In addition, by decreasing the amount of chemicals used, we can develop ecologically sustainable approaches to pest management.

# CHAPTER 3
# EFFECTS OF LIVING AND SYNTHETIC MULCH ON THE POPULATION DYNAMICS OF HOMOPTERAN PESTS, THEIR ASSOCIATED NATURAL ENEMIES, AND INSECT-TRANSMITTED PLANT IMPAIRMENTS

Cucurbits are an important crop in Florida with a farm gate value estimated at over $170 million annually. Currently, production is threatened due to crop plant physiological disorders and insect-transmitted diseases associated with whiteflies and aphids. Control of these key pests has involved the use of several insecticide applications throughout the growing season. However, due to the variable nature of these pests, and problems associated with resistance to insecticides, the management of whiteflies and aphids has become a major problem for growers throughout the world. Additionally, frequent insecticide use has negative impacts on the environment and non-target organisms such as natural enemies.

The use of mulches has successfully reduced population densities of whiteflies and aphids, while also delaying the onset and spread of associated insect-borne diseases. Studies have shown that reflective (synthetic) mulch offers significant protection from these pests compared to bare ground plantings (Brown et al. 1993, Summers et al. 1995, Summers and Stapleton 2002). In addition, studies conducted by Hooks et al. (1998) have shown that living mulches are an effective means for reducing multiple pest complexes and the incidence of associated diseases compared with bare ground. However, there is debate as to which mulching system (i.e., reflective or living mulches) offers the best management potential. A better understanding of pest responses to these systems will help develop new and effective approaches that can be integrated with current management practices.

A number of predators and parasitoids of whiteflies and aphids are known. However, little information is available on how living and synthetic mulches affect insect natural enemies in zucchini crops. To maintain a successful IPM program in cucurbit production, it is essential to know how mulches affect natural enemies that may regulate whitefly and aphid populations. In addition, understanding which natural enemies are present opens the door for future research to be conducted on the efficiency of these insects for control of zucchini pests, and prevents unnecessary efforts to introduce natural enemies that are already present. Discovering which mulching system offers the best habitat for these beneficials could help shape production practices in the future.

Specific objectives for this research were to investigate and compare the effects of reflective (synthetic) and living mulch on the population dynamics of homopteran pests, their associated natural enemies, and insect transmitted plant impairments. In addition, I wanted to investigate the advantages of using living and reflective mulch over the standard (bare ground or white) mulching systems. Field trials were conducted using standard production procedures. Studies were run during the fall growing season because the incidence and severity of both aphids and whiteflies are high at this time, and their effects could be easily examined.

## Methods

### Field Trials

Field research was conducted at the University of Florida, Plant Science Research and Education Unit located in Citra, Florida. Zucchini, *Cucurbita pepo* L., cv. 'Ambassador', were planted on raised beds spaced 1.2 m apart. Zucchini were planted from seed and later thinned to approximately 1 meter between plants. Mulches used during these studies included two synthetic mulches (white and reflective), two living mulches (buckwheat and white clover), and a bare ground control. Buckwheat, *Fagopyrum esculentum* Moench, and white clover, *Trifolium repens* L., mulches were seeded by hand. In 2002, individual plot size was 15 X 14 m and sown with 8 rows. Living mulches were planted after zucchini seeding on top of rows. In 2003 individual plot size was reduced to 14 X 12 m and sown with 7 rows. Living mulches were seeded 1 week before zucchini planting between rows. Treatments were replicated four times in a randomized complete block design with blocks spaced 15 m apart.

Two techniques were used to sample whitefly and aphid adults, 1) traps and 2) sampling the foliage.

**Trap sampling**

Adult whiteflies were monitored using unbaited Pherocon AM traps (Yellow Sticky, YS) placed within interior zucchini rows. Trap heights were adjusted relative to the middle of the plant to improve monitoring efficiency. Each treatment plot contained a total of three YS traps. One trap was placed in the center of the treatment plot, and two others at opposite ends of the treatment plot forming a diagonal line. All YS traps were placed in the field 2 weeks after zucchini planting. YS traps were left in the field for a 24-hour duration once per week until final harvest.

Alate aphids were monitored using blue water pan-traps (Packer Ware bowls, Gainesville, FL). Pan-traps had a diameter of 15.5 cm and contained approximately 250 mL of soapy water. Traps were placed at mid-plant height within interior zucchini rows. Three water pan-traps were used per plot. Traps were placed in the field 2 weeks after zucchini planting. The arrangement of the water pan-traps and the time period in which they were exposed in the treatment plots were similar to YS traps. In 2003, clear water pan-traps (Pioneer/Tri-State Plastics Inc., Dickson, KY) were used in addition to blue pan-traps. Clear pan-traps were square with a diameter of 15.5 cm. One clear water pan-trap was placed in the center of each plot, and treated in a similar manner as the blue pan-traps.

**Foliar Sampling**

Nine plants located on outside rows of each plot were randomly selected for counting adult whiteflies and aphids (apterae and alate). Zucchini plants within the outside rows of plots were chosen, so that any damage that occurred from repeated sampling would be restricted, and not interfere with yield data taken from inside rows. Pest sampling was initiated 4 weeks after planting, and conducted weekly until final harvest. One leaf was sampled per zucchini plant, which was partitioned according to plant stratum (upper n=3; medium n=3, and lower n=3 leaves) allowing a total of nine leaves sampled per plot (36 leaves/treatment). If aphid densities were high (> 100 per leaf), counts were taken from half of the leaf and used to estimate the number on the whole leaf. All whitefly adults, aphids, aphid mummies, and other pest species encountered on the leaf surfaces were recorded.

To estimate the number of whitefly nymphs, 1-inch diameter circular leaf disks were removed using a cork borer from 9 leaves (selected from foliar counts). Leaves were stored in plastic bags, and transported to the laboratory within an ice chest. Leaf disks were removed from one side of a leaf halfway between the leaf tip and petiole, and halfway between the mid-vein and leaf edge (Gould and Naranjo 1999). Leaf disks were removed in the Fruit and Vegetable IPM laboratory, and examined under a 40x-dissecting microscope. All whitefly nymphs encountered on the leaf surfaces were recorded.

Natural enemies were sampled using *in-situ* counts. Leaves from 6 plants located in the outside rows of each plot were randomly selected. In 2002, nine leaves from each plant were randomly selected, and in 2003 six leaves from each plant were randomly selected for visual identification of beneficial arthropods. Sampling was initiated 4 weeks after planting, and conducted weekly until final harvest.

**Physiological Disorder Evaluation**

Visual observations for symptoms of squash silverleaf disorder were recorded weekly from ten randomly selected zucchini plants within the interior rows of each treatment plot. The percentage of plants displaying visual symptoms of silverleaf (silvering on adaxial leaf surface) was taken until final harvest. Silverleaf symptoms were rated on the new leaf growth, with the severity rated on a scale of 0-5 as indicated by Paris et al. (1987).

**Disease Identification**

After harvest of 2003, leaves from four randomly selected plants exhibiting virus infection were collected from each plot, and taken to the University of Florida, Vegetable Entomology Laboratory for disease identification. Each sample was tested for 8 viral diseases (CMV, PRSV-W, SMV, TSV, TSWV, WLMV, WMV-2, ZYMV), using ELISA (enzyme-linked immunosorbent assay) procedures specific for each virus. All plates containing samples were marked for visual positives and read on an ELISA plate reader.

**Statistical Analysis**

Data from arthropod counts and physiological disorder sampling were analyzed using repeated measures analysis of variance (ANOVA). All data were square root transformed, and means separated with least significant differences (LSD) to show treatment differences. Differences were considered significant when $P \leq 0.05$.

## Results

### Trap Sampling

In 2002, YS traps within plots containing white mulch had significantly more whitefly adults, *Bemisia argentifolii*, than the bare ground, reflective, clover and buckwheat treatments (Table 3-1). Traps within buckwheat mulch had significantly fewer adult whitefly populations compared with white, reflective, and bare ground treatments, but similar numbers to clover mulch. Similarly in 2003, YS traps within buckwheat mulch had significantly fewer adult whiteflies than white, clover, and bare ground with the exception of reflective mulch (Table 3-1). Throughout the 2003 season traps within reflective mulch had significantly fewer whitefly adults compared with all other treatments.

During 2002, blue pan-traps within white mulch treatments caught significantly more alate aphids compared with each of the other treatments, which did not differ significantly (Table 3-2). Similarly in 2003, more alate aphids were caught over white mulch compared with all other treatments (Table 3-2). Unlike in 2002, pan-traps within reflective mulch had significantly fewer alate aphids than white, buckwheat, and clover but was borderline insignificant with the bare ground treatment. Similarly, the number of alate aphids trapped in clear pan-traps was also significantly less in reflective than white, bare ground, and clover but was similar to the buckwheat mulch treatment (Table 3-2). In 2003, the total number of alate aphids captured in clear pan-traps compared with the number captured in blue pan-traps was not significantly different ($F$ =3.63, df = 1,470, $P$ = 0.0573). However, when comparing these traps by treatment, significant differences were found between trap types in bare ground using LSD test pairwise comparison ($t$ = -2.76, $Pr > | t | = 0.0060$) (Figure 3-1).

**Foliar Sampling**

In 2002, plants within white mulch had significantly more adult whiteflies than bare ground, buckwheat, and clover but a similar number to reflective mulch (Table 3-3). The number of apterous aphids did not differ significantly between treatments (Table 3-3). Additionally, the number of alate aphids did not differ significantly between treatments (Table 3-3). In 2003, plants grown on bare ground had significantly higher numbers of adult whiteflies than white, reflective, and buckwheat but similar numbers to clover mulch (Table 3-4). Significantly fewer apterous aphids were recorded on plants within reflective mulch than white, clover, and bare ground but similar numbers to buckwheat mulch (Table 3-4). Similarly, significantly fewer alate aphids were recorded on plants in reflective mulch compared with all other treatments (Table 3-4). Data collected from both field seasons reveal that aphids and whiteflies were the dominant pests recorded in the field. In 2002 whiteflies comprised the majority of pest individuals sampled (Figure 3-2), while in 2003, aphids comprised the majority of pest individuals (Figure 3-3). In addition, leaf-mining flies were a minor pest in 2003, but were never recorded in 2002 (Figure 3-2 and 3-3).

In 2002, there were no significant differences in the number of immature whiteflies found between treatments (Table 3-5). In 2003, plants grown on white mulch had significantly higher numbers of immature whiteflies than reflective, clover, and bare ground but similar numbers to buckwheat mulch (Table 3-5). Plant strata played an important role in feeding location of immature whiteflies. Significantly more immature whiteflies were recorded on the lower plant stratum of zucchini plants compared with the middle or top plant strata for all treatments in 2002 (Figure 3-4) and 2003 (Figure 3-5).

In 2002, there were no significant differences in the number of natural enemies found between treatments (Table 3-6). In 2003, clover mulch had significantly higher numbers of natural enemies than white, reflective, and bare ground but similar numbers to buckwheat mulch (Table 3-6). Data collected from both field seasons show that arthropods in the order Araneae were the dominant natural enemy (Figure 3-6 and 3-7). These representations of the percentage of natural enemies found within the field revealed significantly more arthropod diversity in 2003.

**Physiological Disorder Evaluation**

In 2002, significantly more symptoms of squash silverleaf disorder were recorded in plants grown on bare ground than white, clover, and reflective but similar numbers to buckwheat mulch (Table 3-7). Throughout the season plants on reflective mulch had significantly less severe symptoms of silverleaf than all other mulch treatments. Results in 2003 were different from those recorded in 2002. Plants on white mulch had significantly more severe symptoms of squash silverleaf disorder than all other treatments while plants on bare ground and clover mulch had significantly less symptoms (Table 3-7).

**Disease Identification**

Data taken at the end of the 2003 season revealed that two viruses, PRSV-W and WMV-2, were present in the field. ELISA tests found four cases of PRSV-W within plants on the bare ground and clover mulch treatments, and one case each in the white, reflective, and buckwheat mulch. Two cases of WMV-2 were found within plants on the bare ground treatments, and one case in the clover mulch.

## Discussion

During the 2002-2003 field seasons, results from trap catches showed that plants grown on white mulch consistently had higher populations of adult whiteflies and aphids compared to the other mulch treatments including bare ground. These results are consistent with Adlerz and Everett (1968), who showed that white (polyethylene) mulches had higher populations of aphids than both reflective mulch and bare ground. However, it is unclear why whiteflies responded more strongly to white mulch since previous research has shown that they are attracted to yellow colors in the visible light spectra (Mound 1962).

Foliar counts in 2002 showed that whitefly adults were significantly higher in plants grown on synthetic mulches compared to living mulches. However, in 2003 plants on reflective mulch had consistently fewer adult whiteflies and aphids (alate and apterous) compared to other treatments. Foliar counts also revealed that for both years buckwheat performed better than the clover mulch in repelling alate and apterous aphids. Overall, both trap and foliar counts showed that plants grown on reflective and buckwheat mulches consistently had fewer incidences of adult whiteflies and aphids compared with the other mulch treatments including bare ground.

The effectiveness of mulches for controlling immature whitefly numbers, and the incidence of squash silverleaf disorder were inconsistent between years. This may have been due to the fact that whitefly adult and nymph populations were higher in 2002 than in 2003. Similarly, silverleaf severity was higher in 2002 compared with 2003. Overall, reflective mulch performed better at reducing nymphal whitefly populations, and had plants with significantly less incidence of squash silverleaf compared with white mulch.

During 2002 and 2003 it was clear that the location of immature whiteflies was restricted to the lower plant strata for all treatments. These results are consistent with Simmons (1994) who saw 90 to 95% of *Bemisia tabaci* eggs and nymphs on the lower plant strata of various crops. Higher nitrogen content in older leaves (Bentz et al. 1995), or increased protection from pesticides, natural enemies, and environmental factors offered by leaves located on the lower plant strata (Chu et al. 1995, Liu and Stansly 1995), may have played a role in the location of nymphal whiteflies. Similarly, older zucchini leaves have less dense trichomes, which can allow for easier oviposition of eggs, and attachment by feeding immatures (Kishaba et al. 1992, Butler et al. 1986, McAuslane 1996). In either case, these results suggest that for the most efficient sampling of nymphal *B. argentifolii* populations in zucchini, counts should be taken on the lower plant strata.

In 2003, a significant increase in the diversity of natural enemies was seen throughout all treatments. This may have been due to the fact that no insecticides were used throughout the entire field season. In 2002, two reduced-risk insecticides, Admire® and Spinosad®, were applied early to zucchini plants on two separate dates for control of whiteflies and cabbage looper, respectively. Additionally, results in 2003 clearly show that the living mulch treatments had higher natural enemy populations than the synthetic mulch and bare ground treatments. These results support the natural enemies hypothesis proposed by Root (1973) that increased plant diversity leads to increased natural enemy densities. However, there were no differences in the species diversity of natural enemies found between treatments (data not shown).

In 2002, zucchini plants never exhibited visual symptoms associated with viral diseases. This may have been due in part to the low incidence of aphids seen within the field for that year. Despite high aphid numbers and the occurrences of two associated viral diseases in 2003, visual symptoms of WMV-2 and PRSV-W did not occur until the final weeks of harvest, and had little affect on plant growth and yield. Although white mulch had a greater incidence of pests, it had only one case of PRSV-W. Adlerz and Everett (1968) noted that although more aphids were caught over white mulch compared with reflective and bare ground, the incidence of viral diseases was significantly less than the bare ground. They believed that this occurred because one or more of the aphid species attracted to white mulch were not effective in virus transmission. Overall, bare ground and clover mulch treatments had more zucchini plants infected with viral diseases although the numbers were small.

Despite limitations involved with field research (i.e., weather variation and fluctuating pest numbers), patterns were seen in arthropod responses to the different mulch treatments. Overall, results from this research will help to develop successful cultural management practices that establish ecologically friendly measures, which provide growers with sustainable approaches to pest management. In addition, these results can be used to design more extensive studies so that the precise components responsible for insect responses can be determined, and more effective IPM programs can be developed.

Table 3-1. Mean number of adult whiteflies per YS trap in Citra, FL

| | Mean ± SEM | |
|---|---|---|
| | 2002 [a] | 2003 [b] |
| White | 15.54 ± 1.83 a | 3.60 ± 0.46 a |
| Reflective | 9.82 ± 1.24 c | 1.07 ± 0.20 c |
| Buckwheat | 7.71 ± 1.07 d | 1.83 ± 0.23 b |
| Clover | 10.29 ±1.50 cd | 4.60 ± 0.74 a |
| Control | 13.37 ± 1.80 b | 4.25 ± 0.62 a |

Means followed by the same letter are not significantly different ($P$ = 0.05, LSD test)
[a] $F = 13.86$; df = 4, 363; $P < 0.0001$
[b] $F = 30.45$; df = 4, 312; $P < 0.0001$

Table 3-2. Mean number of alate aphids per pan-trap in Citra, FL

| | Mean ± SEM | | |
|---|---|---|---|
| | 2002 [a] | 2003 [b] | 2003 [c] (clear pan-traps) |
| White | 1.47 ± 0.19 a | 0.78 ± 0.10 a | 1.21 ± 0.35 a |
| Reflective | 0.27 ± 0.06 b | 0.17 ± 0.05 c | 0.17 ± 0.08 c |
| Buckwheat | 0.48 ± 0.09 b | 0.44 ± 0.09 b | 0.29 ± 0.11 bc |
| Clover | 0.50 ± 0.09 b | 0.43 ± 0.08 b | 0.83 ± 0.30 ab |
| Control | 0.46 ± 0.09 b | 0.32 ± 0.06 bc | 0.88 ± 0.23 a |

Means followed by the same letter are not significantly different ($P = 0.05$, LSD test)
[a] $F = 16.31$; df = 4, 363; $P < 0.0001$
[b] $F = 8.45$; df = 4, 312; $P < 0.0001$
[c] $F = 4.28$, df = 4, 72; $P = 0.0036$

Table 3-3. Mean number of aphids and whiteflies per zucchini leaf in Citra, FL (2002)

| | Mean ± SEM | | |
|---|---|---|---|
| | Whiteflies (adult) [a] | Aphids (apterous) [b] | Aphids (alate) [c] |
| White | 12.60 ± 2.33 a | 0.54 ± 0.31 | 0.21 ± 0.07 |
| Reflective | 12.31 ± 3.11 ab | 0.15 ± 0.10 | 0.22 ± 0.07 |
| Buckwheat | 5.90 ± 1.60 cd | 0.63 ± 0.38 | 0.13 ± 0.05 |
| Clover | 5.65 ± 1.71 d | 0.24 ± 0.16 | 0.36 ± 0.08 |
| Control | 8.94 ± 1.80 bc | 0.54 ± 0.22 | 0.25 ± 0.08 |

Means followed by the same letter are not significantly different ($P = 0.05$, LSD test)
[a] $F = 7.68$; df = 4, 312; $P < 0.0001$
[b] $F = 1.48$; df = 4, 312; $P = 0.2070$
[c] $F = 2.26$; df = 4, 312; $P = 0.0627$

Table 3-4. Mean number of aphids and whiteflies per zucchini leaf in Citra, FL (2003)

| | Mean ± SEM | | |
|---|---|---|---|
| | Whiteflies (adult) [a] | Aphids (apterous) [b] | Aphids (alate) [c] |
| White | 4.12 ± 0.91 bc | 9.00 ± 3.40 ab | 1.03 ± 0.22 ab |
| Reflective | 2.70 ± 0.68 c | 2.12 ± 0.87 c | 0.06 ± 0.04 c |
| Buckwheat | 2.85 ± 0.76 c | 4.67 ± 1.68 bc | 0.73 ± 0.24 b |
| Clover | 4.61 ± 0.85 ab | 12.61 ± 3.87 a | 2.12 ± 0.69 a |
| Control | 7.33 ± 1.54 a | 7.73 ± 2.17 ab | 1.97 ± 0.52 ab |

Means followed by the same letter are not significantly different ($P = 0.05$, LSD test)
[a] $F = 4.44$; df = 4, 142; $P = 0.0021$
[b] $F = 3.87$; df = 4, 142; $P = 0.0051$
[c] $F = 7.67$; df = 4, 142; $P < 0.0001$

Table 3-5. Mean number of immature whiteflies per leaf in Citra, FL

| | Mean ± SEM | |
|---|---|---|
| | 2002 [a] | 2003 [b] |
| White | 9.20 ± 1.53 | 0.95 ± 0.22 a |
| Reflective | 12.61 ± 2.64 | 0.38 ± 0.11 b |
| Buckwheat | 8.05 ± 1.31 | 0.58 ± 0.15 ab |
| Clover | 7.32 ± 1.23 | 0.35 ± 0.11 b |
| Control | 15.22 ± 2.64 | 0.40 ± 0.10 b |

Means followed by the same letter are not significantly different ($P$ = 0.05, LSD test)
[a] $F$ = 1.68; df = 4, 1032; $P$ = 0.1534
[b] $F$ = 2.55; df = 4, 688; $P$ = 0.0380

Table 3-6. Mean number of natural enemies per leaf in Citra, FL

| | Mean ± SEM | |
|---|---|---|
| | 2002 [a] | 2003 [b] |
| White | 0.04 ± 0.02 | 0.33 ± 0.04 bc |
| Reflective | 0.04 ± 0.02 | 0.26 ± 0.04 c |
| Buckwheat | 0.02 ± 0.01 | 0.41 ± 0.05 ab |
| Clover | 0.01 ± 0.01 | 0.48 ± 0.06 a |
| Control | 0.06 ± 0.02 | 0.28 ± 0.04 c |

Means followed by the same letter are not significantly different ($P$ = 0.05, LSD test)
[a] $F$ = 1.54; df = 4, 1032; $P$ = 0.1886
[b] $F$ = 3.98; df = 4, 560; $P$ = 0.0034

Table 3-7. Mean silverleaf score per treatment in Citra, FL

| | Mean ± SEM | |
|---|---|---|
| | 2002 [a] | 2003 [b] |
| White | 4.09 ± 0.07 b | 1.51 ± 0.06 a |
| Reflective | 3.69 ± 0.09 d | 1.35 ± 0.06 b |
| Buckwheat | 4.20 ± 0.07 ab | 1.10 ± 0.05 c |
| Clover | 3.93 ± 0.10 c | 1.02 ± 0.06 cd |
| Control | 4.39 ± 0.07 a | 0.97 ± 0.06 d |

Means followed by the same letter are not significantly different ($P$ = 0.05, LSD test)
[a] $F = 15.34$; df = 4, 768; $P < 0.0001$
[b] $F = 33.31$; df = 4, 1152; $P < 0.0001$

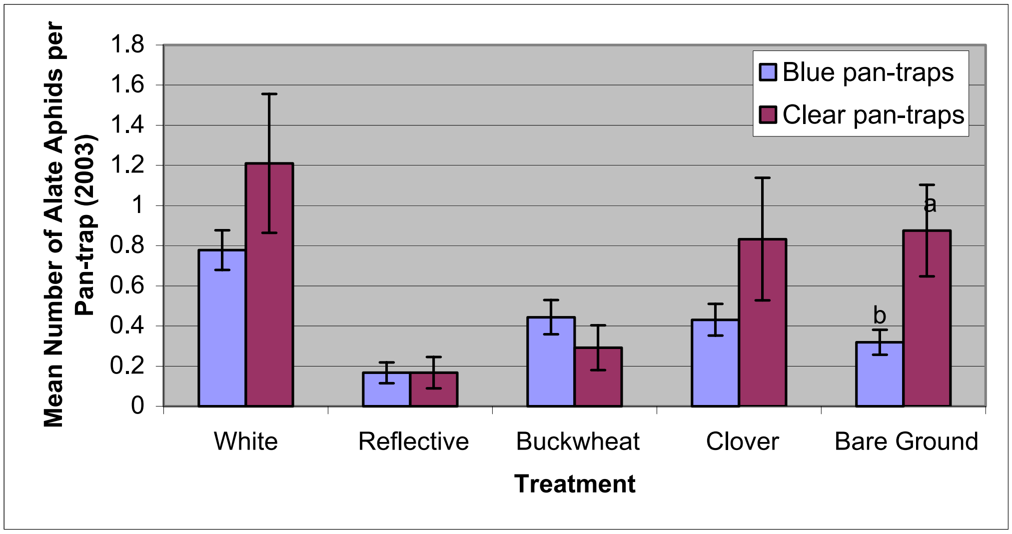


Figure 3-1. Mean number of alate aphids per pan-trap type in Citra, FL (2003)

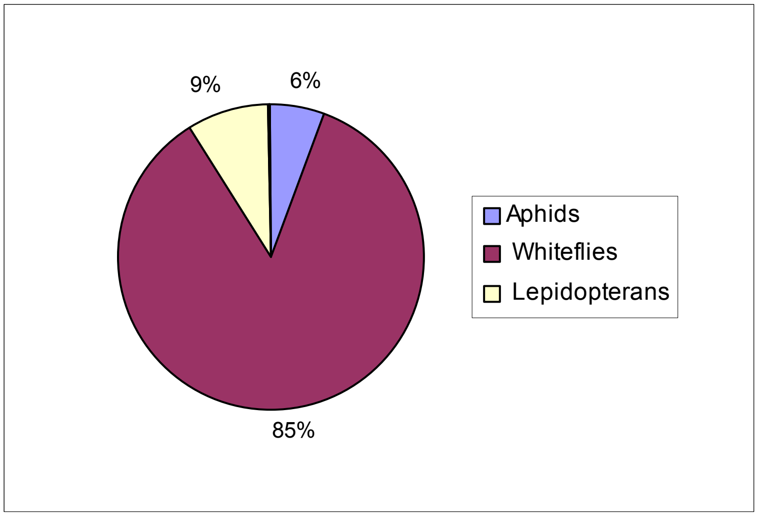


Figure 3-2. Percentage of total pest individuals sampled in Citra, FL categorized by taxon (2002)

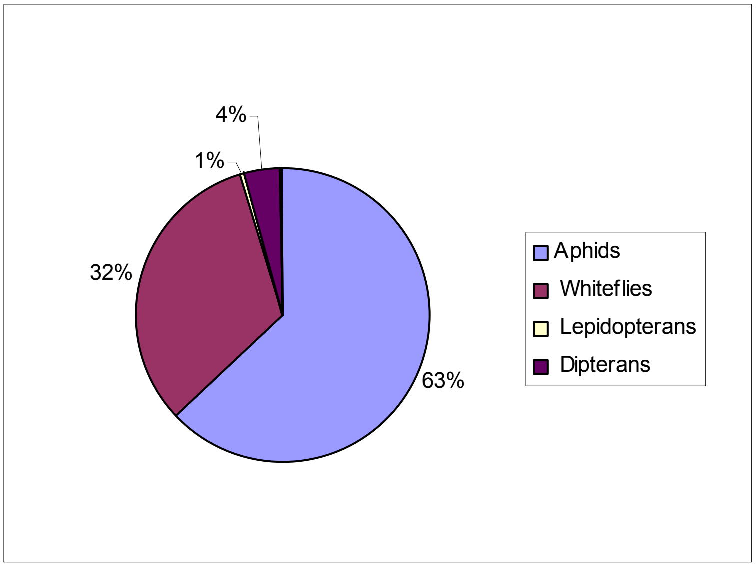


Figure 3-3. Percentage of total pest individuals sampled in Citra, FL categorized by taxon (2003)

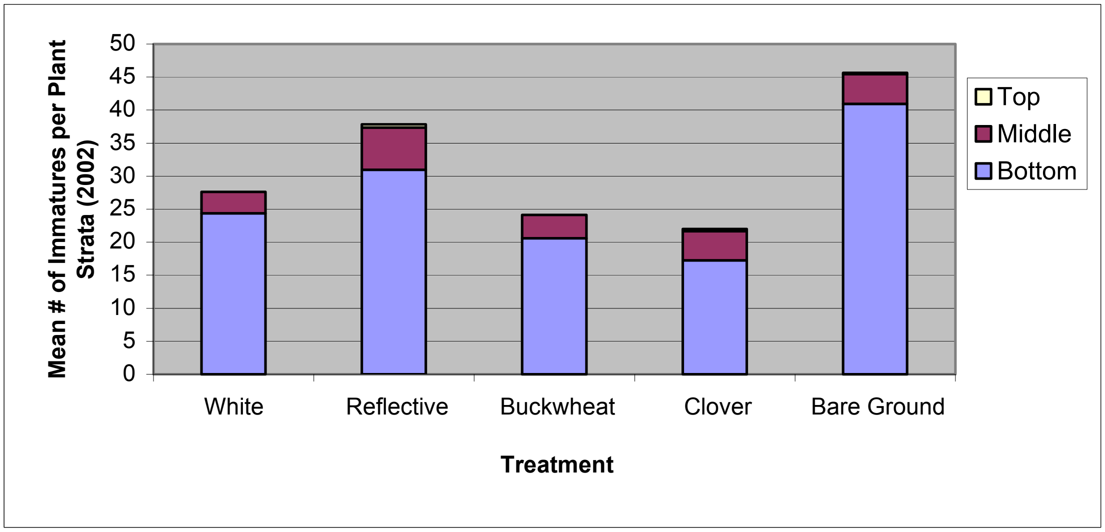


Figure 3-4. Populations of immature whiteflies on zucchini plant strata in Citra, FL (2002)

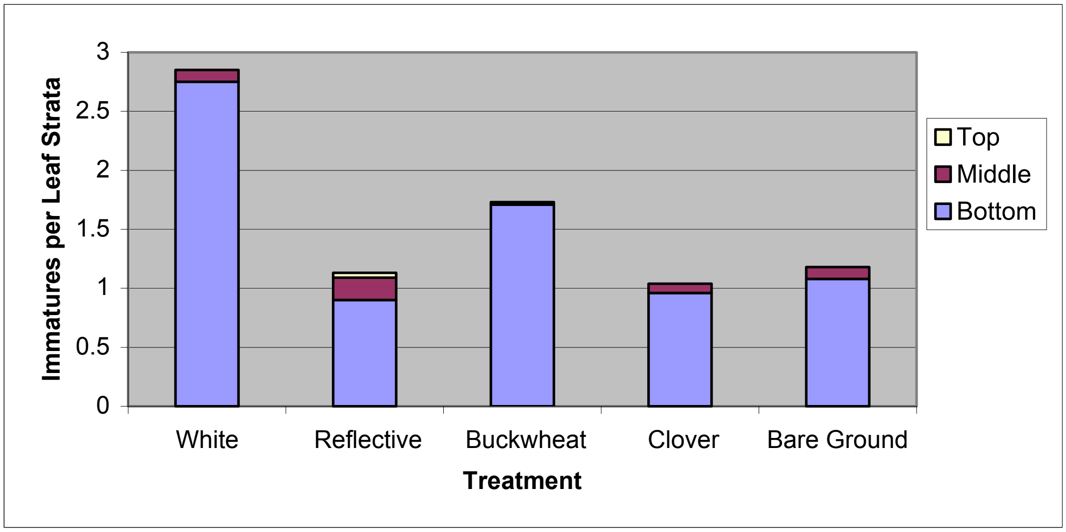


Figure 3-5. Populations of immature whiteflies on zucchini plant strata in Citra, FL (2003)

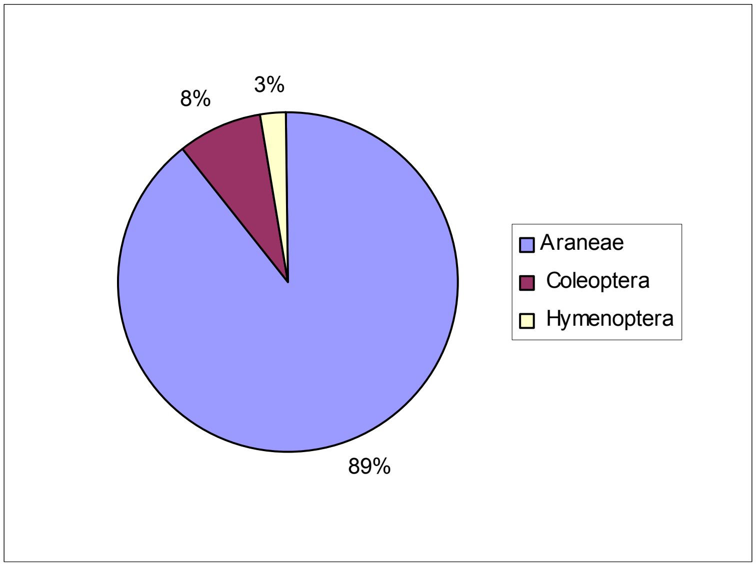


Figure 3-6. Percentage of total natural enemies sampled in Citra, FL categorized by order (2002)

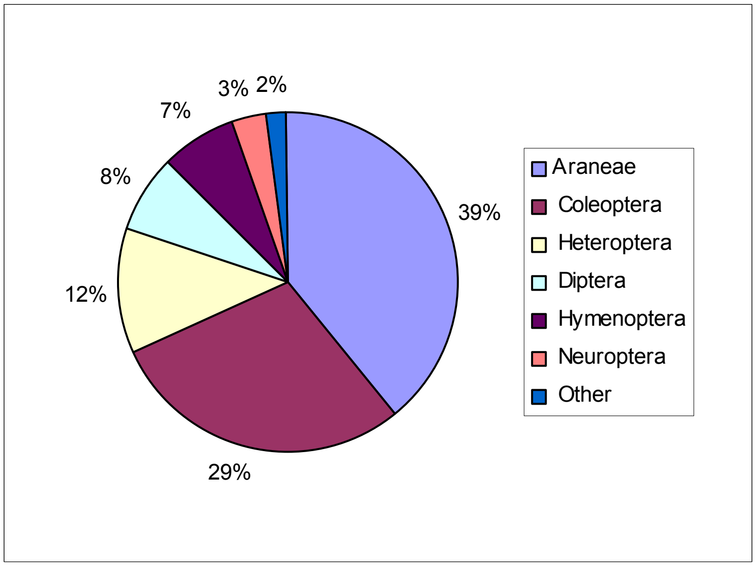


Figure 3-7. Percentage of total natural enemies sampled in Citra, FL categorized by order (2003)

# CHAPTER 4
# IMPACT OF LIVING AND SYNTHETIC MULCHES ON ZUCCHINI PLANT SIZE AND MARKETABLE YIELD

Florida is a major producer of fresh market cucurbits. Currently, production practices involve the use of mulches for control of crop pests, regulation of soil temperature, and weed management. Traditionally, farmers have used white, or white on black mulches in the fall and black in the winter and spring. Although there is no documentation of the use of reflective and living mulches in cucurbits in Florida, these two types of mulches have been used as an alternative to the traditional white or black synthetic mulches in other crops. It is established that living and synthetic mulches can affect the growth and marketable yield of many crops (Andow 1991, Csizinszky et al. 1997, Greer and Dole 2003). However, field studies to compare plant growth and yield in cucurbits are currently lacking.

Synthetic and living mulches repel or attract aphids and whiteflies, and reduce the incidence of associated insect-borne diseases (Chapter 3). In addition, they regulate soil moisture, and temperature, which may lead to increases in above ground plant growth. Plant growth is an important factor in zucchini production because older seedlings are more able to compensate for damage from insect pest attack, and yields are usually not affected (Brewer et al. 1987). Vulnerable stages that limit plant yield occur early during plant development, which makes management of insect pests, and regulation of abiotic factors essential during this period.

Although mulches are used effectively in a number of cropping systems, there may be potential drawbacks depending on the type of mulch chosen for cultural management. For instance, disposal of synthetic mulches following crop termination can be problematic and may interfere with routine farming practices such as cultivation. Additionally, a reduction in the effectiveness of synthetic mulches can occur as the area of foliage increases throughout the growing season (Adlerz and Everett 1968, Csizinszky et al. 1995). Alternatively, living mulches can become problematic because of delayed development and yield reduction from competition between the crop and mulch (Andow 1986). In addition, it is often difficult to choose the proper living mulch that will reduce pest levels, but not interfere with crop growth, yield, or production practices (Hooks and Johnson 2001).

Our goals were to assess the impact of living and synthetic mulches on zucchini plant size and marketable yield. For successful crop management, an understanding of the effectiveness of these mulches is essential. Production practices, which increase economic gains while reducing negative impacts on the environment, are important for the development and integration of management tactics in an IPM program.

## Methods

### Field Trials

Field research was conducted at the University of Florida, Plant Science Research and Education Unit located in Citra, Florida. Zucchini, *Cucurbita pepo* L., cv. 'Ambassador', were planted on raised beds spaced 1.2 m apart. Zucchini were planted from seed and later thinned to approximately 1 meter between plants. Mulches used during these studies included two synthetic mulches (white and reflective), two living mulches (buckwheat and white clover), and a bare ground control. Buckwheat, *Fagopyrum esculentum* Moench, and white clover, *Trifolium repens* L., mulches were seeded by hand. In 2002, individual plots were 15 X 14 m and sown with 8 rows. Living mulches were planted after zucchini seeding on top of rows. In 2003 individual plot size was reduced to 14 X 12 m, and sown with 7 rows. Living mulches were seeded between rows 1 week before zucchini planting. Treatments were replicated four times in a randomized complete block design with blocks spaced 15 m apart.

**Plant Size Sampling**

In 2003, ten plants were selected randomly from the inside rows of each treatment plot after final harvest. Plant dimensions (width and height) were measured in centimeters using a measuring tape. To collect data on plant width we measured from the distal ends of opposing lateral shoots located at the base of zucchini plants. Height data were collected by measuring from the base of zucchini stems to the terminal bud. Results were recorded in the field.

**Yield Sampling**

Inside rows of all treatment plots were evaluated for yield throughout the 2002-03 field seasons. Inside rows were thinned in all plots so that the number of zucchini plants was equal in all rows sampled. During harvest, marketable zucchini from these rows were collected and weighed in the field weekly, and all data were recorded. Harvest sampling continued for 3 weeks in 2002, and for 4 weeks in 2003.

**Statistical Analysis**

Data from plant size sampling were analyzed using ANOVA with means separated using Tukey's test ($\alpha = 0.05$). Data from yield sampling were analyzed using repeated measures analysis of variance (ANOVA). Means were separated with least significant differences (LSD) to show treatment differences. Differences were considered significant when $P \leq 0.05$.

## Results

### Plant Size Sampling

In 2003, data from plant size sampling showed that plants from all mulch treatments were significantly larger than those in the bare ground treatment for width ($F = 19.80$; df = 4, 92; $P < 0.0001$) [Figure 4-1]. All mulched plants were significantly taller than those grown on bare ground, with the exception of those grown with clover mulch, which were not significantly taller ($F = 20.54$; df = 4, 92; $P < 0.0001$) [Figure 4-2]. Plants grown with reflective mulch had dimensions more than 20% larger than those located in bare ground, and were significantly larger than zucchini plants grown with white, buckwheat, and clover mulch.

### Yield Sampling

In 2002, plants in plots treated with reflective and white mulch had significantly higher yields than those in the bare ground, buckwheat, and clover mulch treatments (Table 4-1). In fact, plants grown with white and reflective mulch had 84% and 87% more zucchini fruit than those on bare ground. The situation was even more dramatic when 95% more zucchini fruit were harvested from plants in the white and reflective mulch treatments compared with those grown with living mulches (Table 4-1). Yield data from the 2003 trial were similar although less dramatic. Significantly more zucchini fruit were harvested from plants treated with white and reflective mulch compared with the other treatments (Table 4-1). Unlike 2002, yields from plants treated with living mulch, specifically buckwheat, were only 47% lower than those grown with synthetic mulch. However, plants grown with clover and those on bare ground produced almost two thirds fewer zucchini fruit as plants in synthetic mulch plots.

## Discussion

Throughout the 2002-03 field seasons, plants grown with synthetic mulches had significantly higher yields than those grown with living mulch or on bare ground. Additionally, reflective mulch produced significantly larger plants than all other treatments. Although plants grown with white mulch had significantly higher yields than those with buckwheat mulch, there were no significant differences in plant size. These results show that reflective mulch performed better at both increasing plant size and yield compared with other mulch types evaluated.

Although plants on white mulch consistently had higher aphid and whitefly populations than other mulch treatments (Chapter 3), there were no significant differences between white and reflective mulch when comparing yield. It seems that the added benefits that synthetic mulches provide, such as regulation of soil temperature and moisture, greatly increased plant growth so that the factors associated with homopteran feeding were not a significant issue. Additionally, the deleterious effects of competition from the living mulches on zucchini yield outweighed any positive benefits they may have had on reducing aphid and whitefly pest populations (Chapter 3). Although silverleaf has been known to reduce yields (Costa et al. 1994), it did not appear to be a major factor in this study. This was probably because silverleaf increased in severity when zucchini plants were older. Additionally in 2003, aphid-transmitted viruses did not affect the productivity of zucchini plants because symptoms appeared during the final weeks of harvest.

During both years of the experiment there were challenges in determining the optimum planting time and placement of living mulches within their respective plots. In 2002, living mulches were planted in relatively close proximity to zucchini plants on top of rows. Subsequently, zucchini plants within living mulch treatments were smaller and looked less healthy than those within the synthetic mulch treatments. The close planting of living mulch on top of rows with zucchini plants may have allowed competition for resources (mineral salts and water), which may have stunted plant growth and affected crop yield in these treatments.

In 2003, zucchini yields with living mulch increased substantially from the previous year. This increase can be attributed to planting living mulches between crop rows, and further away from zucchini plants. However, competition may still have been a factor contributing to the significantly lower yields compared with the synthetic mulch treatments.

It was my intention in 2003 to plant living mulches one month earlier than zucchini. We believed that early season establishment of living mulches would reduce yield loss because refuges for natural enemy populations would already be in place during the sensitive stage of early zucchini growth. Unfortunately, heavy rains and wind prevented successful establishment until one week before zucchini planting. In the future, earlier planting dates for living mulches may improve results by increasing zucchini yield. However, further research must be conducted in the timing and location of living mulches within a crop for this method to be used successfully in any IPM program.  Overall, these results show that synthetic mulch (white and reflective) would be more effective for increasing zucchini plant size and yield compared with the other mulch types evaluated.

Table 4-1. Mean yield weight (kg) of zucchini in Citra, FL

| | Mean ± SEM | |
|---|---|---|
| | 2002 [a] | 2003 [b] |
| White | 15.00 ± 1.67 a | 15.36 ± 2.47 a |
| Reflective | 18.24 ± 2.46 a | 15.75 ± 2.21 a |
| Buckwheat | 0.75 ± 0.36 c | 8.07 ± 1.25 b |
| Clover | 0.75 ± 0.38 c | 5.29 ± 0.61 c |
| Bare Ground | 2.36 ± 0.67 b | 5.56 ± 0.83 c |

Means followed by the same letter are not significantly different ($P = 0.05$, LSD test)
[a] $F = 94.04$; df = 4, 36; $P < 0.0001$
[b] $F = 43.07$; df = 4, 48; $P < 0.0001$

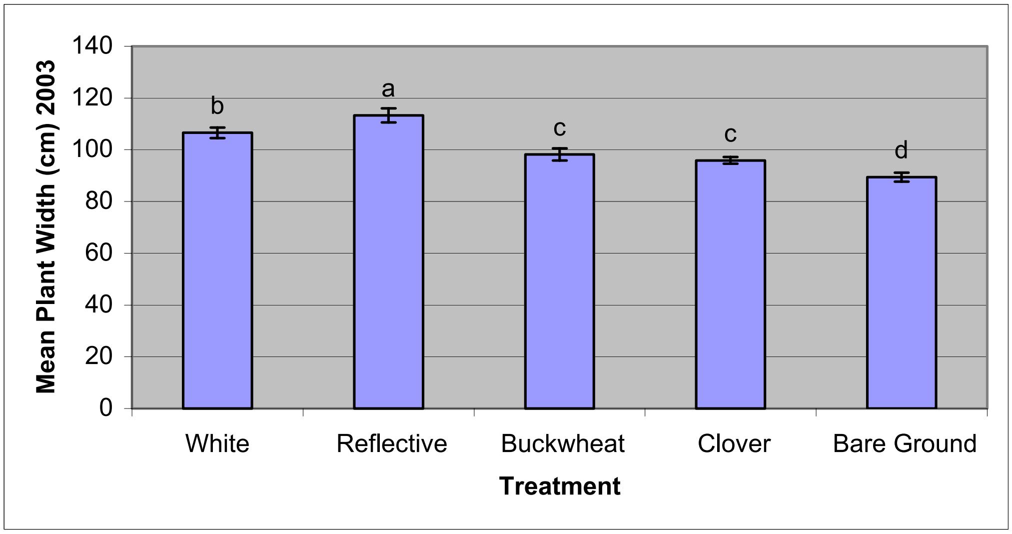


Figure 4-1. Mean plant width (cm) of zucchini in Citra, FL (2003)

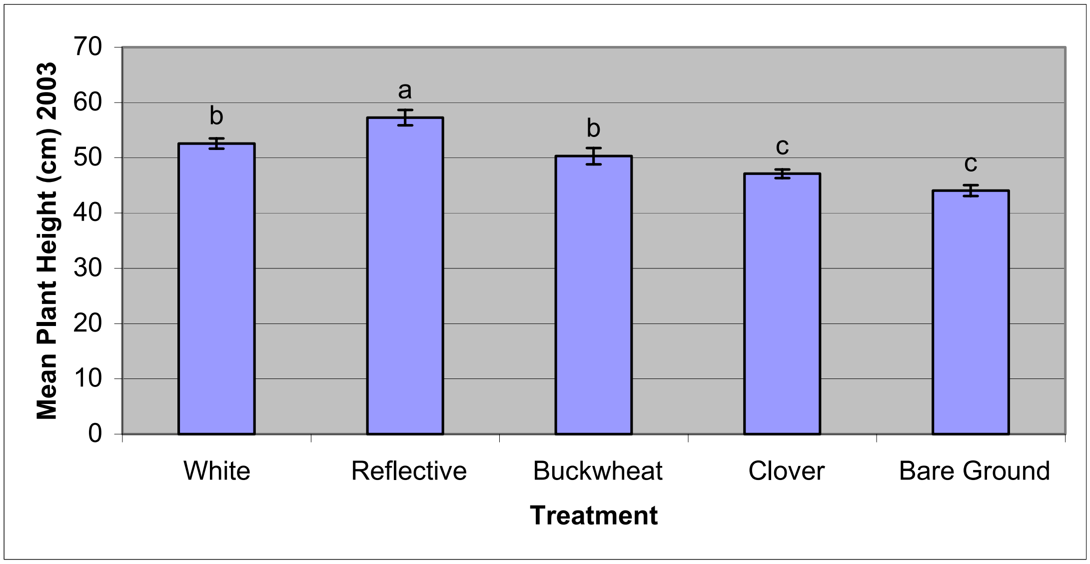


Figure 4-2. Mean plant height (cm) of zucchini in Citra, FL (2003)

# CHAPTER 5
# SUMMARY AND CONCLUSIONS

Research on the effects of different mulching systems within an agroecosystem has allowed improvements to be made in current crop management practices. Reflective mulch has shown clear benefits for pest suppression, and has increased yield for a variety of agricultural crops. Alternatively, living mulches, including buckwheat and clover, have been used successfully for reducing the incidence of aphids and whiteflies, and increasing the number of potential natural enemy species within a variety of crops. In addition, living mulches have been shown to reduce soil erosion and promote chemical free choices for weed management.

Unfortunately, little work has been done in comparing the cost of implementing synthetic versus living mulch. Understanding which mulching system is more efficient for overall cucurbit management will help to develop IPM programs that provide growers with technology that lowers the cost of pest suppression, increases yield, and is more ecologically friendly.

Results from these studies suggest that reflective mulch provided the best overall treatment for reducing whitefly and aphid populations, and the incidence of transmitted diseases. In addition, reflective mulch had significantly larger zucchini plants than other mulch treatments. White mulch had increased whitefly and aphid numbers when compared with reflective mulch, but there were no significant differences in the yield obtained.

Buckwheat mulch performed comparably to reflective mulch in pest suppression, but it had significantly lower marketable yields. Living mulches had significantly higher natural enemy populations compared with synthetic mulches and bare ground. However, synthetic mulches had significantly higher yields compared with living mulches and bare ground.

Economic gains and ease of incorporation play central roles for whether or not a particular tactic is incorporated into an IPM program. Although synthetic mulches provided the highest yields, they cost more when compared with living mulch, or no mulch systems. The cost of buckwheat seeds used for one field season is $37. Although buckwheat is an annual, it can be managed so that it produces seed throughout the year, and does not require subsequent planting later in the season. White clover, a perennial, plus innoculant cost $34 for one field season. Alternately, white mulch cost $120 for a 1.5 X 1829 meter roll, and reflective mulch was $145 for a 1.5 X 1219 meter roll.

Although the costs of living mulches are less than synthetic mulches, they require additional upkeep and management. For instance, living mulches require additional water, and must be maintained so that they don't become a weed problem later in the year. In addition, it is often difficult to determine the best living mulch to use in a cropping system containing multiple pest species.

Overall, synthetic mulches were easier to maintain. They require no establishment period before zucchini is planted, and are not weather dependant. In addition, no special watering features or additional drip lines were needed in plots treated with synthetic mulch. Harvesting zucchini on synthetic mulches was also easier because individual fruits were not concealed by extra vegetation, and competition never played a factor in synthetic mulches as compared to living mulch plots.

When looking at an agroecosystem containing a number of organisms, the complexity of interactions can limit the examination of every interaction simultaneously. Thus, the experiments that were conducted only looked at the most relevant factors involved with whitefly and aphid behavior, so that valid conclusions could be made for future cucurbit management. During the course of my research several challenges arose that may help open the door for future manipulative experiments.

A number of factors can play a role in the fluctuation of insect species. Throughout my research, noticeable differences in weather and temperature were observed between years. These differences may have helped shape the density of whitefly and aphid populations during the course of the experiment. During 2002, whitefly populations were significantly higher than those recorded in 2003 (Figure 1-1 and 1-2). Alternately, aphid populations were significantly higher in 2003 than those recorded in 2002 (Figure 1-1 and 1-2). Despite these yearly fluctuations, definite whitefly and aphid behavioral patterns were observed so that solid comparisons could be made.

Timing and establishment of living mulches were problematic for both field seasons. During 2002, we were forced to plant the living mulch and zucchini at the same time, which may have decreased the effectiveness of living mulch as a refuge for natural enemies early in the season. During 2003, excessive rain postponed the planting date of living mulches until 1 week before zucchini planting. Although this was sufficient time for germination of the living mulch, mature mulch stands did not occur until several weeks after zucchini planting. In the future, early season establishment of living mulches may be helpful in reducing yield loss because refuges for natural enemy populations would have been established during the sensitive stage of early zucchini growth.

Maintaining consistent field borders was difficult in these experiments because research was conducted at an experimental research station. During the 2002 field season, field borders consisted predominantly of grass species. During 2003, grass species were again present, but a plot containing tomatoes was established several weeks before ours on the north border. This tomato plot may have speeded up the migration rates of aphids into our zucchini plots, allowing the spread of viral diseases that may otherwise not have been present.

Currently, management of whiteflies and aphids requires the use of multiple IPM tactics. The use of pesticides, oils, row-covers, and cross-protection in conjunction with mulches may help to limit pest outbreaks and the occurrence of transmitted diseases. By understanding how whiteflies and aphids respond to different mulching systems, we can develop new and effective approaches for integration with current management practices. In addition, further research is needed into the mechanisms involved with this technology, so that future programs can be developed for a variety of other agricultural crops.

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## BIOGRAPHICAL SKETCH

Daniel Lee Frank was born in Salt Lake City, Utah, on January 26, 1978. He graduated from South Sevier High School, Monroe, Utah in May 1996. Shortly after graduation he went to Fort Sill, Oklahoma, where he completed Army basic training and advanced individual training for the Utah Army National Guard. Daniel later attended Utah Valley State College (Orem), where he earned his AS in 1998. He then attended Utah State University (Logan), where he earned his BS in biology (with a minor in chemistry) in 2001. After graduation Daniel traveled extensively throughout South America. Upon his arrival back to the United States, he decided to pursue a MS in entomology at the University of Florida in 2002. After completing his degree requirements, Daniel plans on working for a government agency conducting research in integrated pest management (IPM).