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# Effect of living (buckwheat) and UV reflective mulches with and without imidacloprid on whiteflies, aphids and marketable yields of zucchini squash

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The silverleaf whitefly, B biotype of the sweetpotato whitefly, *Bemisia tabaci* Gennadius also known as *B. argentifolii* Bellows and Perring, and the melon aphid, *Aphis gossypii* Glover, are key pests of zucchini squash in Florida. The use of mulches, living or synthetic, is one of the tactics that could be used to suppress whitefly and aphid populations and their associated transmitted viruses. Buckwheat, *Fagopyrum esculentum* Moench – a living mulch, and a synthetic, UV reflective mulch, were evaluated alone or in combination with a reduced-risk insecticide, imidacloprid Admire® 2F in two field experiments carried out during the Autumn of 2005 and 2006. Four 80-$m^2$ plots were used for each treatment with standard white mulch as a control in a randomized complete block design. Imidacloprid was applied at planting and buckwheat mulch was planted approximately 2 weeks before the squash was seeded. Addition of imidacloprid to the mulches significantly reduced the number of whiteflies and apterous aphids in 2005 but not in 2006. In 2005, there were treatment differences on natural enemies' abundances where more natural enemies were recorded within buckwheat mulch than reflective mulch. Squash within synthetic mulches resulted in significantly higher yields than those grown with living mulch. We conclude that imidacloprid can be used with the mulches to manage whiteflies and aphids in zucchini squash when the pest populations are high, but this may not necessarily translate in economic benefits in terms of yields.

**Keywords:** *Fagopyrum esculentum*; UV reflective mulch; *Cucurbita pepo*; *Bemisia tabaci*; *Aphis gossypii*

## 1. Introduction

Zucchini squash, *Cucurbita pepo* L. is a high value vegetable crop in Florida, USA. In the 2005–2006 field-seasons the value of production was estimated to be $39 million USD (NASS-2006). In Florida, damage due to pest infestations is the major problem affecting the squash industry. The silverleaf whitefly, B biotype of sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) – also known as *B. argentifolii* Bellows and Perring, and the melon aphid, *Aphis gossypii* Glover, are the key pests of zucchini squash in Florida (Frank and Liburd 2005; Liburd and Nyoike 2007a, 2007b; Nyoike et al. 2008). They damage squash plants both directly by removing their sap and indirectly by transmitting viruses, and/or lowering produce quality due to the growth of moulds on the insects' honeydew.

The first report of economic damage associated with silverleaf whitefly in cucurbits was recorded in Florida in 1988 (Schuster et al. 1991). Over the years, *B. tabaci* has increased its importance as a direct pest and also as a vector of plant viruses, particularly geminiviruses (Geminiviridae: Begomovirus). The silverleaf whitefly is now considered to be one of the most damaging pests of squash. Recently, it has been implicated in the transmission of three squash-related viral diseases in Florida including Squash vein yellowing virus (SqVYV) (Adkins et al. 2007), Cucurbit leaf crumple virus (CuLCV) (Akad et al. 2008), and Cucurbit yellow stunting disorder virus (CYSDV) (Polston et al. 2008).

Aphids are known for non-persistently transmitting most of the economically important viruses that infect squash (Zitter et al. 1996). The most common aphid-transmitted viruses in Florida include Watermelon mosaic virus, Zucchini yellow mosaic virus, Papaya ringspot virus and occasionally, Cucumber mosaic virus (Webb et al. 2003).

The management of aphids with contact and systemic insecticides has little influence on the incidence of virus-transmitted diseases because the viruses are transmitted before aphids can acquire a lethal dose (Zitter et al. 1996; Walters 2003). Similarly, management of whiteflies with insecticides is problematic because all whitefly life stages occur on the undersides of leaves making it difficult to reach them with contact pesticides. Nevertheless, insecticides can be used to constrain the proliferation of viruses by preventing pest population build-up on the host.

The use of polyethylene plastic mulch on raised beds is a common practice in the production of high value vegetable crops (Waterer 2000). In Florida, growers use black for winter and spring seasons to increase soil temperature and white-on-black mulch in the Autumn to reduce soil temperature (Zitter and

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Simons 1980). Mulches have several advantages including controlling weeds, increased yields, earliness in crop yields, and pest management (Lament 1993). In particular, UV reflective mulch has received increased attention in the production of various crops because they lower insect infestations and reduce insect-transmitted diseases (Brown et al. 1993; Summers et al. 2004; Nyoike et al. 2008). However, synthetic mulches introduce additional costs of production for material, installation and problems associated with removal and disposal of mulches (Lament 1993).

Living mulches are potential alternatives to synthetic mulches in selected vegetable production systems. When interplanted with a cash crop, living mulches offer various benefits such as improving soil fertility, suppressing weeds and reducing pest populations (Liburd et al. 2008). Living mulches create a more diverse community that can reduce insect herbivore populations by attracting natural enemies of the pests or by reducing the host plant's apparency to the pest (Root 1973). Previous research reported a reduction in insect pest populations when zucchini plants were grown with living mulches in Florida (Frank and Liburd 2005) and Hawaii (Hooks et al. 1998).

Our hypothesis was that the use of a reduced-risk insecticide with a living or synthetic mulch could result in further reduction in pest populations and thus lead to economic gains in terms of increased yields. Specific objectives were to investigate the effect of a living mulch buckwheat (*Fagopyrum esculentum* Moench), and a UV reflective mulch in combination with imidacloprid (Admire® 2F, Bayer, Kansas City, MO) to manage whiteflies and aphids in zucchini squash.

## 2. Materials and methods

### 2.1. Experimental layout

Field experiments were conducted during the Autumn of 2005 and 2006 at the University of Florida, Plant Science Research and Education Unit in Citra, Florida. Experimental plots consisted of five 10.4-m long rows that were 1.06 m apart. Plants were grown on 30-cm high and 76-cm wide beds. Living mulch, buckwheat and UV reflective mulch were evaluated alone, or in combination with imidacloprid (Admire® 2F Bayer, Kansas City, MO) that was applied through the irrigation drip lines 10 days after germination at the rate of 1.684 L. Treatments were arranged in a randomized complete block design with four replicates. The specific treatments were: (1) UV reflective mulch with imidacloprid; (2) UV reflective mulch without imidacloprid; (3) buckwheat (living mulch) with imidacloprid; (4) buckwheat without imidacloprid; and (5) white mulch ((control) and grower standard).

Living mulch seeds were hand-sown on 21st and 18th September in 2005 and 2006, respectively, into shallow furrows that were prepared by a hand furrower (Lowe's, Gainesville, FL). Plots with the living mulch treatment were provided with two extra drip lines to adequately irrigate buckwheat plants. Other land preparation and management procedures are described in detail in Nyoike et al. (2008).

Zucchini squash (WildCat® variety) were hand-seeded approximately 92 cm apart during the two growing periods. In both years, zucchini was planted approximately 2 weeks after planting buckwheat. At the time of planting squash, the buckwheat mulch was approximately 20 cm high and there were two rows of buckwheat on each side of the squash plants (Figure 1a). In the case of synthetic mulches (UV reflective and white) the entire 76 cm on the top bed surfaces were covered with the mulch (Figure 1b). To ensure a uniform squash stand within each treatment missing plants were replaced within the week after germination using already established seedlings from the greenhouse.

## 3. Insect pests sampling

### 3.1. Aphids

Nine plants were randomly selected from each plot for visual observations. Alate and apterous aphids (adults


Figure 1. (A) Zucchini squash growing with living mulch. (B) Zucchini squash growing on UV-reflective mulch.

and immatures) were counted from the leaves *in situ* by the leaf-turn method. The latter involved gently turning over a leaf and counting the number aphids observed. A total of 36 leaves per treatment was counted. This foliar sampling was initiated 3 weeks after planting and carried out weekly until final harvest.

In addition to the leaf turn method; alate aphids were monitored using blue (PackerWare®) and clear water pan-traps (Pioneer/Tri-State Plastics Inc., Dickson, KY). Both clear and blue pan traps were used to determine if trap color could affect aphid catch. A total of four pan traps were used per plot, two of each color, placed at the four corners of each plot within the interior rows. Each pan trap contained approximately 250 $cm^3$ of 5% detergent solution (Colgate-Palmolive Co., New York, NY). Each trap was supported on a tomato cage and trap height was adjusted according to plant height. The traps were left in the field for 1 week and sampling was conducted for 7 and 6 weeks in 2005 and 2006, respectively. In 2005, the number of alate aphids trapped was taken in the field, while in 2006 bowl contents were emptied into individual vials and labeled accordingly. Vials were then transported to the University of Florida, Small Fruit and Vegetable IPM Laboratory in Gainesville, FL for counting.

### 3.2. *Whiteflies*

Adult whiteflies were monitored with yellow sticky, Pherocon® AM unbaited traps (YST) (Great Lakes IPM, Vestaburg, MI). Three traps were placed in each plot, one in the middle and the other two on a diagonal line at the two opposite sides of the plot. The traps were left in the field for 24 h then taken to the laboratory to perform counts. The first sets of traps were placed into the field 1 week after germination and thereafter once every week for 8 and 6 weeks in 2005 and 2006, respectively.

The size of the nymphal whitefly population was determined from the nine selected leaves (discussed above), three from each plant stratum (upper, mid, lower) (Frank and Liburd 2005). The leaves were excised and placed in 1-gallon self-sealing Ziploc bags and returned to the laboratory. A 3.14-$cm^2$ leaf disc was taken from each leaf using a cork borer and examined for whitefly immature stages under a dissecting microscope at 40 × (MEIJI EMZ, Meiji Techno Co. Ltd Tokyo, Japan).

### 3.3. *Silverleaf symptoms*

In 2006, symptoms of silverleaf on squash were assessed on 10 plants within the interior rows of each plot. Squash with silverleaf symptoms were scored using an arbitrary scale adapted from Yokomi et al. (1990) where an index of zero signified a 'healthy' plant with no symptoms and an index of 5 all leaves were completely silvered.

### 3.4. *Natural enemy counts*

Natural enemies were sampled using *in situ* counts. Six leaves from six plants located on the outside rows of each plot were randomly selected for sampling to prevent disturbance to natural enemies. The leaves were gently turned and the number of natural enemies (predators, parasitoids) encountered were recorded. Sampling for natural enemies began 3 weeks after planting and then conducted every other week until the final harvest.

### 3.5. *Plant size sampling*

Ten plants were randomly selected from the inner rows that had not been damaged during pest sampling to estimate plant size. Plant size measurements were taken using a technique adopted from Frank and Liburd (2005). Using a tape measure, plant height was measured from the ground to the terminal bud. The plant width data were taken by measuring the length between the two widest opposing lateral shoots growing from the same plant.

### 3.6. *Zucchini squash yields*

Yield data were collected from the three inner rows of each plot that had not been damaged during sampling. Zucchini squash was harvested at immature stage (soft, thin, edible rind shells) with edible seeds at approximately 20–25 cm long. Fruits were harvested and weighed in the field every other day for 3 weeks.

### 3.7. *Data analysis*

Data from whitefly and aphid counts were analyzed using repeated measures analysis (PROC MIXED, SAS Institute 2003) to examine interaction effects between treatment and time (sampling weeks). Least square mean values were computed and means were compared to determine the effects of mulch treatments. The standard errors of means (SEM) were also calculated.

Data from natural enemy counts, silverleaf score index, plant size and yield data were subjected to ANOVA using PROC GLM (SAS Institute 2003) and treatment means were separated using LSD (SAS Institute 2003). Where necessary, the data were log-transformed to meet the assumptions for ANOVA. Comparisons of immature counts from the treatments were made based on the average of upper, middle and lower leaf disc counts.

## 4. Results

### 4.1. *Aphid populations*

Significantly fewer apterous aphids (adults and immatures) were counted on squash leaves grown with buckwheat and reflective mulch with imidacloprid than all the other treatments evaluated ($F_{4,72} = 10.42$; $P < 0.0001$) (Table 1). The addition of imidacloprid to the mulches reduced the number of apterous aphids per leaf but not alate aphids. There were significant ($F_{20,72} = 3.37$; $P < 0.0001$) interaction effects between treatment and sampling weeks for apterous aphids. Of the 6 weeks sampled, treatment differences were observed in 3 of the 6 weeks. Similarly, there were significant ($F_{20,72} = 2.40$; $P < 0.0036$) interaction effects between treatment and time for alate aphids counted per leaf. Among the weeks sampled, treatment differences were only observed in 2 weeks of sampling, and during both dates reflective mulch with imidacloprid had the highest number of alate aphids per leaf. Overall, reflective mulch with imidacloprid recorded significantly higher number of alate aphids per leaf compared with all the other treatments except reflective mulch alone ($F_{4,72} = 5.13$; $P < 0.0011$) (Table 1). The major aphid species recorded were melon aphid, *Aphis gossypii* Glover and green peach aphid, *Myzus persicae* Sulzer.

In 2006, the results were similar to those observed in 2005, both buckwheat and reflective mulches with imidacloprid had fewer apterous aphids than other treatments ($F_{4,72} = 3.14$; $P < 0.0193$) (Table 1). Significant ($F_{20,72} = 2.01$; $P < 0.0166$) interaction effects between treatment and time were observed during 2 weeks of sampling. Buckwheat with and without imidacloprid had significantly fewer alate aphids than the white mulch (control), which was similar to the reflective mulches. Similar to 2005, the addition of imidacloprid did not affect the number of alates per leaf when used with any of the mulches (buckwheat or reflective).

During the 2-year study, the color of the pan traps (clear versus blue) did not have a significant ($t = -0.86$, $\Pr > |t| = 0.3908$) in 2005 and ($t = 0.03$, $\Pr > |t| = 0.9736$) in 2006 effect on trap catches and hence means of pooled alate aphid counts are reported here. In 2005, pan traps within reflective mulch with imidacloprid caught significantly higher numbers of alate aphids than those in the white mulch (control), which did not differ significantly from those in reflective mulch and buckwheat treatments ($F_{4,268} = 2.51$; $P = 0.0392$) (Table 2).

In 2006, pan traps within the white synthetic mulch caught significantly more alate aphids than all other treatments ($F_{4,84} = 9.54$; $P < 0.0001$) (Table 2). Like the foliar counts, the addition of imidacloprid did not affect the number of alate aphids captured. Significant ($F_{4,84} = 3.63$; $P < 0.0001$) interaction effects between treatment and time were observed in weeks 2 and 4, respectively.

### 4.2. *Whiteflies (adult)*

In 2005, significantly fewer adult whiteflies were captured on yellow sticky traps (YST) within the reflective mulch treatment with imidacloprid compared with all other treatments ($F_{4,96} = 22.21$; $P < 0.0001$) (Table 3). Buckwheat alone was not significantly different from the white mulch (control). There were significant ($F = 4.26$; df = 28, 72; $P < 0.0001$) interaction effects between treatment and sampling weeks. Treatment differences were observed in 6 out of the 8 weeks sampled. For most of the sampling dates, white

Table 2. Effect of living and reflective mulches alone or in combination with imidacloprid on the number of alate aphids trapped per pan-trap in Citra, FL.

| Mulch treatment | Mean ± SEM counts per pan trap 2005[1] | 2006[2] |
|---|---|---|
| Reflective + Imidacloprid | 3.07 ± 0.43 a | 2.69 ± 0.45 b |
| Reflective | 2.36 ± 0.36 ab | 1.94 ± 0.32 c |
| Buckwheat | 2.14 ± 0.27 ab | 2.91 ± 0.45 b |
| Buckwheat + Imidacloprid | 2.21 ± 0.28 ab | 3.19 ± 0.57 b |
| White (control) | 1.97 ± 0.28 b | 3.83 ± 0.53 a |

Means followed by the same letter are not significantly different. [1]$F = 2.51$; df = 4, 268; $P < 0.0392$. [2]$F = 9.54$; df = 4, 84; $P < 0.0001$.

Table 1. Effect of living and reflective mulches alone or in combination with imidacloprid on the number of aphids per zucchini squash leaf, Citra, FL in 2005 and 2006 (Foliar counts).

| | Mean ± SEM aphid numbers per leaf | | | |
|---|---|---|---|---|
| | 2005 | | 2006 | |
| Mulch treament | Apterous (wingless)[1] | Alate (winged)[2] | Apterous (wingless)[3] | Alate (winged)[4] |
| Reflective + Imidacloprid | 0.56 ± 0.21 b | 0.92 ± 0.29 a | 0.04 ± 0.02 b | 0.25 ± 0.06 ab |
| Reflective | 3.48 ± 0.80 a | 0.69 ± 0.21 ba | 0.28 ± 0.12 a | 0.17 ± 0.05 ab |
| Buckwheat | 3.19 ± 1.02 a | 0.31 ± 0.06 c | 0.21 ± 0.09 ab | 0.16 ± 0.04 b |
| Buckwheat + Imidacloprid | 0.44 ± 0.12 b | 0.37 ± 0.06 bc | 0.01 ± 0.01 b | 0.14 ± 0.04 b |
| Control | 3.07 ± 0.69 a | 0.40 ± 0.10 bc | 0.31 ± 0.11 a | 0.29 ± 0.08 a |

Means followed by the same letters are not significantly different. [1]$F = 10.42$; df = 4, 72; $P < 0.0001$. [2]$F = 5.13$; df = 4, 72; $P < 0.0011$. [3]$F = 3.14$; df = 4, 72; $P < 0.0193$. [4]$F = 0.86$; df = 4, 72; $P < 0.6330$.

Table 3. Effect of living and reflective mulches alone or in combination with imidacloprid on the number of adult and immature whiteflies on zucchini squash in Citra, FL.

| | Mean $\pm$ SEM aphid numbers per leaf | | | |
|---|---|---|---|---|
| | Adult whiteflies per YST | | Immature whiteflies per leaf disc (3.14 cm$^2$) | |
| Mulch treatment | 2005[1] | 2006[2] | 2005[3] | 2006[4] |
| Reflective + Imidacloprid | 10.74 $\pm$ 1.67 c | 13.22 $\pm$ 1.54 d | 0.33 $\pm$ 0.10 c | 0.30 $\pm$ 0.09 c |
| Reflective | 20.80 $\pm$ 3.81 b | 27.82 $\pm$ 4.41 b | 1.86 $\pm$ 0.32 b | 0.98 $\pm$ 0.26 bc |
| Buckwheat | 31.92 $\pm$ 6.36 a | 18.90 $\pm$ 3.30 c | 2.11 $\pm$ 0.46 b | 1.77 $\pm$ 0.45 b |
| Buckwheat + Imidacloprid | 17.33 $\pm$ 3.11 b | 12.01 $\pm$ 1.29 d | 0.42 $\pm$ 0.15 c | 0.44 $\pm$ 0.20 c |
| Control | 51.33 $\pm$ 11.32 a | 37.72 $\pm$ 4.71 a | 3.49 $\pm$ 0.77 a | 2.83 $\pm$ 0.64 a |

YST data (2005) whitefly data transformed ($\log_{10}$) before analysis, means are presented in the original counts. Means followed by the same letter are not significantly different. [1]$F = 22.21$; df = 4, 96; $P < 0.0001$. [2]$F = 27.66$; df = 4, 72; $P < 0.0001$. [3]$F = 13.91$; df = 4,72; $P < 0.0001$. [4]$F = 11.90$; df = 4, 72; $P < 0.0001$.

mulch (control) resulted in the highest number of whiteflies counted per trap.

In 2006, the addition of imidacloprid to buckwheat and reflective mulches resulted in significantly fewer adult whiteflies compared with the mulches tested alone ($F_{4,72} = 27.66$; $P < 0.0001$) (Table 3). There were significant ($F_{20,72} = 3.79$; $P < 0.0001$) interaction effects between treatment and sampling weeks (4 of the 6 weeks sampled). Yellow sticky traps within the buckwheat alone treatment had significantly ($P < 0.05$) fewer adult whiteflies than reflective alone and white mulch (control), which was higher than all the other treatments.

### 4.3. *Whiteflies (nymph)*

Results of whitefly immature counts in the laboratory indicated that most of the whitefly nymphs were concentrated in the lower plant stratum with the least on the upper stratum. In 2005, white mulch had significantly higher numbers of immature whiteflies per 3.14-cm$^2$ leaf disc compared with all the other treatments ($F_{4,72} = 13.91$; $P = 0.0001$) (Table 3). Treatments with imidacloprid contained the fewest number of whitefly immature per leaf disc. Buckwheat alone was not significantly different from reflective mulch alone. There were significant ($F_{4,72} = 2.91$; $P = 0.0005$) interaction effects between treatment and time throughout the sampling period.

In 2006, the addition of imidacloprid to mulches resulted in a significant reduction of whitefly immatures only when used with buckwheat mulch and not with reflective mulch ($F_{4,72} = 11.90$; $P < 0.0001$) (Table 3). However, buckwheat mulch with imidacloprid was not significantly different from reflective with imidacloprid and reflective alone. As in 2005, white mulch resulted in significantly higher numbers of immatures per leaf disc compared with all the other treatments. The interaction effect between treatment and time was significant ($F_{20,72} = 1.90$; $P < 0.0255$) in 4 out of the 6 weeks sampled.

### 4.4. *Silverleaf disorders*

Silverleaf symptoms differed significantly among the treatments ($F_{4,34} = 44.60$; $P > 0.001$). Plants growing within white mulch had almost the entire upper leaf surface silvered as indicated by the high index score (Figure 2). Treatments with imidacloprid (reflective and buckwheat) had significantly lower index scores than all other treatments. There was no difference between reflective mulch and buckwheat treatment alone.

### 4.5. *Natural enemies*

The major families of natural enemies recorded throughout the study were Syrphidae, Coccinelidae, Chrysopidae, and Araneae. In 2005, significantly more natural enemies were recorded on squash in the buckwheat treatment with imidacloprid than any other treatment except buckwheat alone ($F_{4,353} = 3.43$; $P = 0.009$) (Table 4). Reflective mulch with imidacloprid had the fewest natural enemies but it was not significantly different from reflective mulch alone. In 2006, the population of natural enemies were lower and there were no significant differences among the treatments ($F_{4,347} = 0.69$; $P < 0.6006$) (Table 4).

### 4.6. *Plant size*

Plant widths for reflective mulch treatments with and without imidacloprid were significantly larger than the buckwheat treatment ($F_{4,34} = 11.64$; $P < 0.0001$) (Table 5). Buckwheat treatments resulted in the smallest width and there was no significant difference between treatments with and without imidacloprid.

Zucchini plant height grown in reflective mulch with and without imidacloprid was not significantly different. However, these plants were significantly taller than all other treatments, including the control (Table 5). Zucchini plants grown within living mulch with imidacloprid were significantly taller than plants grown in living mulch alone, a treatment that resulted in the

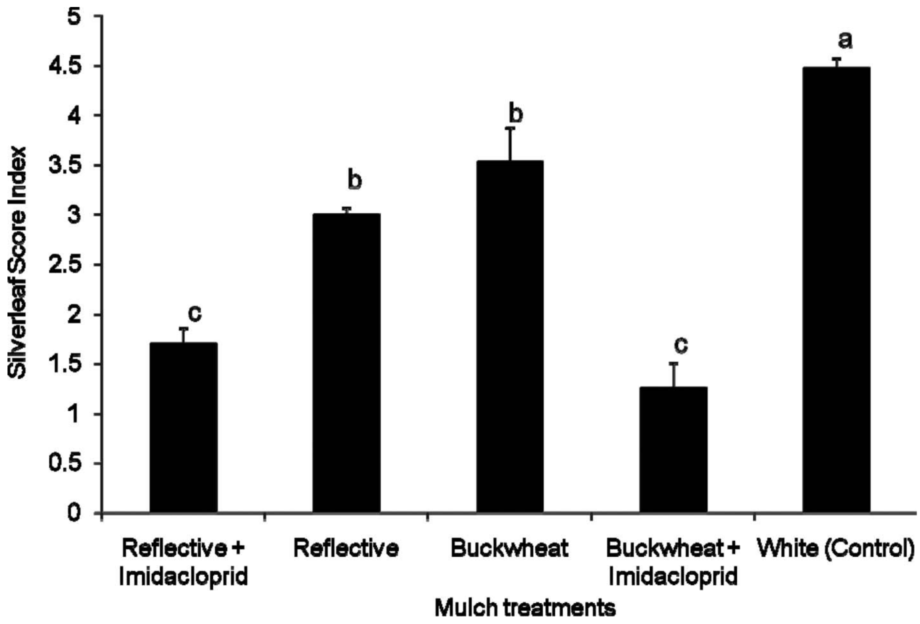


Figure 2. Effect of living and reflective mulches alone or in combination with imidacloprid on silverleaf symptoms presented by the score indices per treatment in zucchini Citra, FL (2006).

Table 4. Effect of living and reflective mulch alone or in combination with imidacloprid on number of natural enemies per treatment in zucchini Citra, FL.

| | Mean natural enemies per treatment ± SEM | |
|---|---|---|
| Mulch treatment | 2005[1] | 2006[2] |
| Reflective + Imidacloprid | 0.18 ± 0.06 c | 0.21 ± 0.07 |
| Reflective | 0.26 ± 0.06 bc | 0.15 ± 0.04 |
| Buckwheat | 0.40 ± 0.08 ab | 0.29 ± 0.09 |
| Buckwheat + Imidacloprid | 0.49 ± 0.08 a | 0.23 ± 0.06 |
| White (control) | 0.28 ± 0.06 bc | 0.26 ± 0.06 |

Means followed by the same letter are not significantly different $P = 0.05$ (LSD). [1]$F = 3.43$; df = 4, 353; $P < 0.009$. [2]$F = 0.69$; df = 4, 347; $P < 0.6006$.

least height when compared with all the other treatments ($F_{4,34} = 41.92$; $P < 0.0001$) (Table 5).

### 4.7. *Zucchini squash yields*

Zucchini squash yields differed significantly among the treatments ($F_{4,167} = 37.56$; $P < 0.0001$) (Table 5). In 2005, zucchini plants grown with reflective mulch with imidacloprid produced significantly higher yields than those from buckwheat and white mulch (control) treatments. Overall, plants growing within reflective and white mulch treatments had 58 and 54%, respectively, more zucchini than those growing in the living mulch. Reflective mulch alone and white mulch provided similar yields.

Similarly, in 2006, reflective mulch plots produced significantly higher yields than the white mulch (control) ($F_{4,133} = 53.40$; $P < 0.0001$) (Table 5). Overall, reflective mulch treatment resulted in the highest yields compared with all the other mulches. As in 2005, buckwheat plots produced the least yields when compared with all the other treatments. Plants growing within the living mulch alone produced 74 and 64% fewer marketable squash than those within reflective and white mulches, respectively.

## 5. Discussion

Our study shows that living and reflective mulches in the absence of imidacloprid were able to provide some protection to zucchini against whiteflies. The addition of imidacloprid to reflective and living mulches further reduced the populations of whiteflies (adults and immatures) in both years. However, the reduction in whitefly population did not result in increased yield, thereby rejecting our hypothesis. Overall, UV-reflective mulch resulted in significantly higher marketable yields than buckwheat treatments, whose yields were lower than the white synthetic mulch (control).

### 5.1. *Effects of mulches on arthropod populations*

The addition of imidacloprid did not enhance the reduction of alate aphids as revealed by the pan traps and foliar counts. Previous studies have reported that UV-reflective mulch was able to confuse and repel alate aphids preventing them from landing on summer squash (Brown et al. 1993; Summer et al. 2004). Our pan-trap results in 2006 were in agreement with previous research where the reflective mulch alone afforded the best protection against alate aphids. In contrast, the addition of imidacloprid to reflective mulch provided a significant amount of control for apterous aphids in 2005 and

Table 5. Effect of living and reflective mulches alone or in combination with imidacloprid on plant size and marketable yields of zucchini squash.

| | Mean ± SEM aphid numbers per leaf | | | |
|---|---|---|---|---|
| | Plant size (2006) | | Mean yield per treatment (kg) | |
| Mulch treatment | Width[1] | Height[2] | 2005[3] | 2006[4] |
| Reflective + Imidacloprid | 42.08 ± 2.00 a | 23.71 ± 0.39 a | 39.47 ± 4.07 a | 32.97 ± 3.42 a |
| Reflective | 40.09 ± 1.94 ab | 22.15 ± 0.69 a | 36.26 ± 3.87 ab | 32.11 ± 3.67 a |
| Buckwheat | 31.62 ± 1.54 c | 13.75 ± 0.58 d | 15.1 ± 2.70 d | 8.29 ± 1.21 c |
| Buckwheat + Imidacloprid | 32.64 ± 1.81 c | 16.10 ± 0.73 c | 20.39 ± 3.59 c | 8.54 ± 1.47 c |
| Control | 38.18 ± 2.00 b | 18.39 ± 0.70 b | 33.45 ± 3.62 b | 23.37 ± 2.35 b |

Means followed by the same letter are not significantly different. [1]$F = 11.64$; df = 4, 34; $P < 0.0001$. [2]$F = 41.92$; df = 4, 34; $P < 0.0001$. [3]$F = 37.56$; df = 4,167; $P < 0.0001$. [4]$F = 53.40$; df = 4, 133; $P < 0.0001$.

2006. Imidacloprid is a systemic insecticide (Palumbo et al. 2001) and could be more lethal to apterous aphids that are sedentary as opposed to the migrating alate aphids. Zalom (1981) also recorded high numbers of apterous aphids on head lettuce with aluminum mulch compared with bare ground.

Although previous studies have reported reduction of whiteflies when using living mulch (Hooks et al. 1998; Frank and Liburd 2005; Hilje and Stansly 2008), none of these studies evaluated living mulch in combination with a reduced-risk insecticide (Admire® 2F). According to the US Environmental Protection Agency (EPA 1996) mandate, a reduced-risk insecticide poses minimal harm to human and other non-target organisms and the environment as compared to a non-reduced risk insecticide. Hilje and Stansly (2008) reported that tomato plants grown with ground covers including living and reflective mulches compared favorably well with a conventional insecticide treatment (evaluated separately) when they assessed the number of whiteflies and virus incidence in tomatoes. In our studies, the addition of imidacloprid to the living mulch (buckwheat) further reduced whitefly populations (adults and immatures). The reduction in the number of immature whiteflies per leaf is important since they are responsible for inducing silverleaf symptoms (Schuster et al. 1991). In our studies, silverleaf symptoms were more severe in the white mulch treatment, which also had the highest whitefly population compared with all the other treatments. In addition, high numbers of aphids have been trapped in plants on white polyethylene mulch compared with bare ground or/and other mulches (Alderz and Everett 1968; Zitter 1977; Zitter and Simons 1980; Frank and Liburd 2005). In Florida, white mulch is used alone or on top of black in zucchini production. A positive correlation between the number of whitefly immatures and SSL symptoms has been reported previously (Costa et al. 1993).

In 2005, more natural enemies were recorded on plants growing with living mulch (buckwheat) than those with UV reflective mulch with imidacloprid. However, in 2006 no significant differences among the treatments were recorded, which was probably due to the lower population of natural enemies recorded during that year. The natural enemies counted on the leaves were mainly predators and consisted of Syrphids, Coccinelids, Chrysopids and spiders. Spiders made up the bulk (39%) of the recordings followed by coccinelids (29%). Buckwheat is an annual plant whose flowers produce nectar that can potentially attract large numbers of beneficial insects including pollinators. Inclusion of a living mulch within a cash crop is known to diversify habitats increasing the number of herbivores and their natural enemies, which potentially contribute to pest reduction in these habitats (Root 1973).

### 5.2. *Effect of mulches on plant size and marketable yields*

Zucchini plants interplanted with the living mulch, buckwheat, were smaller in size and eventually yielded less than those growing on the synthetic mulches. Our results were consistent with the findings of Frank (2004) where plants growing with buckwheat mulch were smaller and had lower yields than those grown with synthetic mulches. When living mulches are interplanted with a main crop (zucchini) they share the same scarce natural resources (e.g. light, nutrients), which could lead to competition that can negatively affect the production of the main crop. In our study, competition between zucchini plants and buckwheat was observed to be greatest during the early stages of growth. Plants growing within the buckwheat treatment had delayed flowering responses and a setback in their harvesting period (personal observation). Although squash plants were observed to regain some level of vigorous growth after buckwheat senesced, they were not able to compensate for yield. It is possible that early-season competition is a critical factor that could affect fall zucchini production when interplanted with living mulches. Nevertheless, plants grown with living mulch have been reported to increase yields in tomatoes (Hilje and Stansly 2008). Some adjustments in plant spacing (between living mulch and zucchini) and time of planting may increase marketable yields but more research in this area is needed.

The reflective mulch treatment had the largest plants and the highest yields. Previous studies have reported similar findings (Brown et al. 1993; Summers et al. 1995; Csizinszky et al. 1997; Stapleton and Summers 2002; Summers et al. 2004; Frank and Liburd 2005). It is known that UV-reflective mulch has high photosynthetically active radiation, which contributes to both plant growth and crop earliness (Stapleton and Summers 2002).

## 6. Conclusion

The use of imidacloprid in combination with mulches enhanced the control of whiteflies and apterous aphids in the zucchini plantings. Generally, living and reflective mulch with imidacloprid gave equal protection against whiteflies and aphids. However, despite reducing pest numbers, the use of living mulch resulted in low yields, which may be related to plant competition. This adverse effect of the living mulch (buckwheat) may limit its adoption in pest management programs until more research is conducted to determine correct plant spacing, as well as time of planting. In treatments where imidacloprid were used, the lack of yield increase in squash may indicate that its usefulness may not be warranted if UV reflective mulch is being used. However, the observed lower reductions in pest numbers (whiteflies and apterous aphids) may result in reduce frequency for virus transmission, which ultimately can increase marketable yields under a commercial operation.

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