EFFECTS OF COLOR TO DETER THRIPS AND REDUCING THE INCIDENCE OF

TOMATO SPOTTED WILT VIRUS

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EFFECTS OF COLOR TO DETER THRIPS AND REDUCING THE INCIDENCE OF TOMATO SPOTTED WILT VIRUS

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EFFECTS OF COLOR TO DETER THRIPS AND REDUCING THE INCIDENCE OF TOMATO SPOTTED WILT VIRUS

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Mallory Jones Kelley was born on December 30, 1984 in Selma, Alabama and is the daughter of Alan and Harriette Jones and has two sisters, Kalee and Lauren and is married to Ron Kelley. She graduated from John Tyler Morgan Academy in May 2003 and entered Auburn University in August 2003. Mallory graduated with a Bachelor of Science degree in Horticulture in May 2007. Then she entered graduate school at Auburn University in May 2007 and pursued a Master of Science Degree under the guidance and direction of Dr. Wheeler G. Foshee, III. While at Auburn, Mallory was employed as a graduate research assistant and later as a graduate teaching assistant. She received her Master of Science Degree on May 9, 2009.

THESIS ABSTRACT

EFFECTS OF COLOR TO DETER THRIPS AND REDUCING THE INCIDENCE OF TOMATO SPOTTED WILT VIRUS

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A field study was conducted to evaluate the influence of colored mulch plastic on thrips ability to locate tomatoes (*Lycopersicon esculentum* Mill.). Mulch colors were selected based on ultra violet reflectance which has been shown to repel thrips. Specially manufactured colored mulches (Pliant Corp, Washington, GA) were: silver, red 1, red 2, black, and violet. Thrips population counts and plant yields were taken weekly. Enzyme-linked immunosorbent assay (ELISA) tests were completed early-season and mid-season to test for tomato spotted wilt virus (TSWV). Statistical anaylsis revealed that the colored mulches did effect thrips counts measured by cup and flower sampling, marketable weight, marketable count, and TSWV incidence. The silver colored mulch was consistently lower in cup counts of thrips than all other treatments and black mulch had the highest cup count of thrips. The silver mulch had the least number of flower

thrips than any other treatment and the violet mulch had the highest flower thrips. Silver mulch had higher marketable weight and marketable fruit count then all other treatments followed by the violet mulch, but the violet mulch had less incidence of TSWV than the silver. The standard black mulch had the lowest marketable weight and marketable fruit count than all other treatments. In the later test for TSWV, red 1 and violet colored mulches similarly had the lowest percentage of TSWV incidence and black mulches had the highest percentage of TSWV incidence.

A field study was conducted to evaluate the influence of Blue-X Growtube Shelters on the ability of thrips to locate tomatoes (*Lycopersicon esculentum* Mill.). Blue-X Shelters (BLUE-X® Enterprises, Inc., Sacramento, CA) with varying tube sizes were selected for this study: 13”x9”, 13”x6”, 18”x9”, and 18”x6”, along with a non-treated control. Thrips population counts, yields, and height measurements were taken weekly. Enzyme-linked immunosorbent assay (ELISA) tests were completed early-season and mid-season to test for tomato spotted wilt virus (TSWV). Statistical anaylsis revealed that the Blue-X growtubes did lower thrips cup counts in the early season. No difference was seen in the flower counts taken later in the season. The marketable weight and marketable fruit counts were effected by the treatments. The non-treated control plots had the highest marketable fruit weight and marketable fruit counts over all the tube treatments. The 18”x6” and 18”x9” had the lowest marketable fruit weight and marketable fruit count. TSWV was highest in the 18”x6” tubes in the early season test than any other treatment. In the later testing 13”x6” tubes had the highest amount of TSWV incidence of any other treatment. Plant height was effected by the treatments. All tube treatments were taller than the control plots.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Thrips were first described by De Geer in 1744, with the four known species placed in the genus Thrips by Linneaus in 1758. The term thrips is used for both the single and plural form of the insect. Thrips were placed in the order Thysanoptera in 1836 by the English entomologist, Haliday, but Linnaeus is still credited with classification of all insects in this order. To date there are more than 5,000 species of thrips recognized and placed into two suborders and eight families (Lewis, 1997a). Of these 5,000 species, very few are recognized as serious crop pests, however, the significance of thrips as a pest has encouraged more research and study and the measures needed in control.

Thrips occur worldwide, but are more commonly found in temperate and tropical areas of the globe. Thrips have very small slender bodies $\leq$1 mm long, and are poor flyers with delicately fringed wings and long cilia. Thrips vary in color from straw-yellow to brown, with the variation being due to stage of development (Zitter and Daughtrey, 1989).

Temperature and rainfall seem to play a major role in thrips populations. Heavy precipitation tends to have a negative affect in that it can kill the larvae and suppress dispersal. Rainfall may positively affect thrips population, growth and dispersal by delaying senescence of host plants, allowing thrips more time to produce and colonize host plants (Morsello et al., 2008).

The primary goal of most vegetable farmers is to produce a healthy, marketable crop for consumers. Feeding of thrips causes damage that leads to discoloration, deformities, and reduced marketability of the crop. Thrips are known to cause economic damage to many crops including cabbage, cotton, onion, tomato, pepper, peanut, and tobacco. Thrips damage can be caused directly by thrips feeding, or indirectly by transmission of plant viruses (Morsello et al., 2008).

Thrips feed on plant material using piercing and sucking mouthparts on the leaves and the flowers of host plants. In order to feed, thrips pierce plant cells with a mandible stylet to create an entry hole into the plant, after which the c-shaped maxillary stylets join together to form a tube, which enters the cell to suck out the contents (Lewis, 1997b).

A type of thrips known as *Frankliniella occidentalis*, the western flower thrips, damage plants by feeding on leaves and flowers and vectoring tospoviruses such as: impatient necrotic spot virus (INSP) and tomato spotted wilt virus (TSWV) (Blumthal, et al., 2005). Western flower thrips and *Frankliniella fusca*, tobacco thrips, are known vectors of TSWV, but virus transmission, population dynamics, host plant use, and behavior can all differ among species of thrips (Momol, et al., 2004).

Geographical locations affect the specificity and distribution of western flower thirps and tobacco thrips, both of which occur in the United States, Mexico, and as far north as Canada. In Europe and the United States, western flower thrips are recognized as the major vector of TSWV and INSP (Zitter and Daughtrey, 1989).

Western flower thirps not only spread TSWV and INSV, they also serve as a virus host. Western flower thrips and tobacco thrips vectoring of TSWV can damage the foliage of pre-flowering tomatoes (<8 wk old). Young tomato plants infected with TSWV results in lower yield and a higher percentage of damaged fruit than plants that are infected later in the growing season (Joost and Riley, 2008).

Thrips can only acquire TSWV in the larval stage where the virus inoculates for 3-10 days before transmission can occur (Zitter and Daughtrey, 1989). Once thrips become infected with TSWV they can transmit the virus for the remainder of their life. Of the various species of thrips, western flower thrips cause tomato growers in the southeast the greatest economic loss.

Western flower thrips have many biological characteristics making control extremely difficult. The first larval stage of the western flower thrips only lasts 1-2 days, and then the second larval stage lasts 24 days. In this second stage, thrips are feeding and are capable of transmitting the viruses. At the end of the second larval stage, the insect stops feeding and moves into the soil or leaf litter to pupate. The insect then goes through a prepupal stage (1-2 days) and pupal stage (1-3 days) before becoming an adult. Adult thrips can survive 30-45 days and lay 150-300 eggs each. WFT feeds mainly on flowers and plant terminals where they are protected, which makes control even more difficult (Zitter and Daughtrey, 1989).

In a study completed in the Netherlands, an immunohistological technique was used to show where TSWV was located inside thrips species. The only organs where TSWV accumulated were in the midgut, foregut, and salivary glands. The study showed that the site of TSWV infection within a thrips occurs in various tissues, and the potential of transmission seems to be regulated by barriers and processes related to the metamorphosis of thrips. Each population of thrips shows different physiological potentials to replicate and transmit TSWV (Nagata et. al., 1999).

Eight species of thrips in two genera, *Frankliniella* and *Thrips*, are reported to transmit TSWV and are known to infect more than 1,000 plant species (Joost and Riley, 2008). TSWV is the most important of the viruses transmitted by thrips. TSWV is the only member of an RNA-containing virus group that has membrane-bound spherical particles 70-90mm in diameter (Zitter and Duaghtrey, 1989).

The primary spread of TSWV is from adult thrips that are carriers of the virus to the crop from sources such as weed hosts. Weed hosts should be eliminated in controlling thrips population because they serve as a reservoir for TSWV (Zitter and Daughtrey, 1989). Secondary spread usually occurs by thrips colonizing and reproducing on the current seasons crop or nearby weed hosts. Limited secondary spread of TSWV occurs within tomato and pepper fields with primary spread the most significant (Momol, et al. 2004).

A plants morphology, chemistry, and physiology changes as the plant grows. Changes that occur in a plant affect the feeding behavior of herbivores. Younger plants are usually higher in nitrogen concentration than older plants. Greenhouse studies have indicated the importance of nitrogen to thrips feeding. Western flower thrips were shown to select tomato flowers with high nitrogen content over those with moderately nitrogen levels in the field (Stavisky et al., 2002).

Younger plants usually have a higher defense mechanism than older plants; however, younger plants are more susceptible to viruses. Seasonal growth of a tomato plant could alter the feeding and settling behaviors of thrips, and ultimately alter the thrips efficiency to transmit TSWV (Joost and Riley, 2008).

Symptoms of TSWV will vary in the tomato plant depending on the stage of infection. Some host plants of TSWV will develop symptoms within 5 days of being infected. Symptoms will appear visually on leaves, petioles, stems, and fruit. Symptoms on tomatoes appear in the form of yellow or brown ringspots on the fruit, brown streaks on the petioles or stem, stunted growth, necrotic leaf spots, tip dieback, premature fruit ripening, and one sided growth (Zitter and Daughtrey, 1989).

To specifically identify TSWV, special laboratory tests are required. An ELISA (enzyme-linked immunosorbent assay) is a serological test most commonly used. The ELISA test is the most accurate of all tests for TSWV, but false negatives are still possible. More reliable tests are still being developed to detect all strains of TSWV (Zitter and Daughtrey, 1989).

Taking accurate counts of thrips populations is important for research purposes and reducing variability within a study. Generally, four different sampling techniques are used in collecting thrips for population counts: with an aspirator, the beat-cup, vile flower collecting, and an insect vacuum device. The most commonly used and accurate of these methods are the aspirator and the beat-cup method (Cloyd, et al., 2001).

Aspirators were designed to increase the efficiency for detection of infestations and minimize variability within experiments. Aspirators are most commonly used to collect thrips from plant tissue and then inoculate plants for study purposes (Cloyd, et al., 2001). The beat-cup method was studied in 2000 in comparison to other collecting methods and proved to be the most precise in counts of thrips populations (Joost and Riley, 2004).

Plants contain different pigments including chlorophyll, carotene, and xanthophylls, which can respond to different wavelengths of light. Natural sunlight peaks in the visible region of the electromagnetic spectrum between 380 and 740 nm. Light of different wavelengths can have different effects on plant growth. Most plants responses are regulated by red and blue light. Blue light triggers a phototropic response and green light has a negative effect on plant growth. Plants are able to detect even a slight change in light composition through their photoreceptors. Light quality is mainly sensed by the presence of different light receptors specific for different wavelengths. Photoreceptors function as signal transducers to provide information that controls physiological and morphological responses (Rajapakse et al., 1999).

Decoteau et al., (1997) have studied the manipulation of light environments to regulate chrysanthemum development using spectral plastics at Clemson University in South Carolina. Wilson and Rajapakse (2001a) studied *Eustoma grandiflora* (Lisianthus) to measure plant response to photo selective plastic films with varying spectral transmission properties. Plant response to photo selective plastic films with varying spectral distribution properties was also studied using three sub-tropical perennials (Wilson and Rajapaske, 2001b). Experiments also correlated the response of chrysanthemum plants to light environment based on various quantitative light quality parameters by growing plants under 6% or 40% $CuSO_4$ and water spectral filters (Rajapakse et al., 1992). The results from these studies indicate that a plants response to different types of films and filters can be beneficial to the nursery and landscape industry in multiple ways.

Tree shelters are tubes made of a translucent polypropylene film, which is placed around tree seedlings or transplants at planting time (Burger et al., 1992). Tree shelters increase temperature, humidity, and CO_2 concentrations which are believed to cause increased growth in trees. The quick establishment of small trees results in lower costs (Svihra et al., 1993). The use of plastic tree shelters for low cost establishment of street trees showed that height and caliper of all the tree species that were tested equaled or exceeded trees without tree shelters (Jones et al., 1996). Tree shelters bring the greatest impact to tree seedlings and transplants in the first two years, then the shelters should be removed (Gerhold, 1999).

Blue-X growtube shelters (BLUE-X® Enterprises, Inc., Sacramento, California) are used in the nursery industry as grape shelters, tree shelters and with direct seeding. Blue-X shelters enable plants to make full use of nature's beneficial blue light to increase stem diameter and to accelerated growth. Blue-X shelters create a beneficial microclimate within the shelter with higher temperatures and humidity levels (Frearson and Weiss, 1987). Shelters consistently increase survival rates and growth rates, but effects can differ among species (Potter, 1991). Shelters are thought to increase the height and diameter of trees in less time due their ability to increase the length of the growing season (Minter, et al., 1992). Tree shelters were evaluated as a means of accelerating height growth of tree-form crapemyrtles. In two experiments grown in shelters the crapemyrtle (*Lagerstoemia indica* 'Dynamite' TM), 'Whit II' were 124% and 48% taller at the end of the growing season. 'Potomac' was 61% and 50% taller while its caliper was 35% less. The crapemyrtle cultivar 'Tuscarora' was not affected by the tree shelters. Also the study found that all plants grown in tree shelters flowered later than unsheltered plants and appear to have straighter, more upright trunks with minimal lateral shoot development (Brooks, 2006). These shelters shorten production time in some cultivars by enhancing height growth or improving plant forms. Tree shelters have also been found to have a high level of ultraviolet reflectance within the plastic material. The level of reflectance shown in this material seems beneficial in the search for a product to repel thrips.

Multiple control tactics for thrips and TSWV management have been simultaneously evaluated. To understand the epidemiology of TSWV it is important to understand the relationship between the vector, virus, and weed hosts. A better understanding of these aspects is important in determining the most effective control method for thrips and TSWV.

Several different management practices have been studied for controlling thrips, these including insecticide treatments, horticulture oils and insecticidal soaps, planting times of the host plant, host plant resistance, colored traps, predatory mites, and colored mulch. None of these methods alone have shown to successfully control thrips populations (Zitter and Daughtrey, 1989).

In order for insecticide treatments to be beneficial, early detection of a thrips population is crucial. Chemical control involves many important steps such as selecting the proper insecticides, frequency of applications, researching for the best application method, and having a pesticide rotation plan (Zitter and Daughtrey, 1989). The most widely used insecticide program for thrips consists of broad-spectrum insecticides. Insecticides registered for thrips control include organophosphates, carbamates, chlorinated hydrocarbons, and botanicals (Zitter and Daughtrey, 1989). Imidacloprid and spinosad are the two most commonly used insecticides for thrips control. Application of imidacloprid on tomato transplants may offer some protection, but not complete control of the thrips population (Riley and Pappu, 2000). Spinosyns are insecticides that excite neurons in the central nervous system of an insect and cause involuntary muscle contractions. This insecticide ultimately paralyzes the insect due to neuromuscular fatigue. Currently no evidence of field resistance to spinosad within western flower thrips populations exists (Loughner, 2005).

Insecticides should be applied with equipment that produces very small particles (<100 microns). The intensely small particles allow the insecticide to penetrate deep into the areas of the plant harboring thrips, and provide the most effective impact on the thrips population (Zitter and Daughtrey, 1989). With so few insecticides available to control thrips, rotating insecticide chemicals is important in order to delay insecticide resistance.

Western flower thrips species have a short generation time which creates the need for repeated application. Excessive insecticide use, in conjunction with multiple insect generations per year, increases the possibility of insect populations developing resistance to specific insecticides (Immaraju et. al., 1992).

Horticultural oils and insecticidal soaps have been shown to interfere with both mechanical and insect transmission of viruses, through control of aphids, leaf miners, mealybugs, mites, scales, and whiteflies. However, no evidence has been shown that these oils and soaps have any effect on controlling the western flower thrips (Allen et. al., 1993).

Planting date was shown by Riley and Pappu, (2000) to have an effect on TSWV incidence in South Georgia. The later planted tomatoes resulted in higher TSWV incidence, lower thrips numbers, and lower tomato yields both in fruit quality and marketability. Early plantings on black plastic with an intensive insecticide treatment resulted in the highest yield (Riley and Pappu, 2000). However, Croxton (2008) observed anecdotally that early planted tomatoes in central Alabama were higher in TSWV incidence than later planted tomatoes. This conflicts with Riley and Pappu (2000) results that showed that earlier planted tomatoes had less TSWV incidence than later planted tomatoes. Riley and Pappu (2000) showed that even though the late planting date avoided thrips, it did not avoid transmission of TSWV. The overall percentage of TSWV-positive was no different between symptomatic and asymptomatic plants at harvest. Furthermore, Culbreath et al., (2003) reported that no single management tool provides adequate control and resistant varieties are the most important factor in reducing incidence of TSWV.

In 2000, TSWV-resistant tomatoes by BHN Research Incorporated were released. These resistant varieties were 'BHN-444', 'BHN-555', and 'BHN-640.' The creation of these resistant varieties was successful; however the resistant variety is not appealing in taste. In return, this does not contribute much to the growers market (Riley and Pappu, 2004).

Traps for thrips or other insects are used to monitor thrips presence or absence according to different plant hosts and seasonal changes. Many studies have been conducted on the trapping of thrips. Factors that influence the efficiency of thrips traps include color of traps, trap orientation, height of trap above the crop, color around the trap, and volatile chemicals to traps. The addition of volatile chemicals is known to increase thrips capture (Teulon, et al., 1993). The use of traps for western flower thrips with p-anisaldehyde has been reported to be helpful in early season monitoring (Teulon, et al., 1993).

Predatory mites have been recommended in controlling western flower thrips. *Neoseiulus cucumeris* is a predacious mite used in studies at a rate of 53 mites/m^2 /week. Studies have shown that predatory mites alone do not have a strong enough impact on thrips populations for management. Combinations of tactics have been used in attempt to lessen the population of thrip. The use of the insecticide spinosad alone was a better control than using the predatory mites alone. The use of both spinosad and mites together did not show a significant improvement over the treatments of spinosad alone. Higher rates of mites have been used in studies to determine if this would result in a greater impact on the thrips populations. A higher rate of 190 mites/m^2 /week still only provided partial control of western flower thrips and the control by spinosad was still more significant. The benefit to using predators over chemicals is still important, since no resistance could be developed (Van Driesche, et al., 2005).

Certain species of insects have been shown to depend on UV light to orient themselves during flight and also recognize host plants. Studies suggest that thrips vary in their color preference, but are usually more attracted to light colors. Also highly reflective surfaces repel most thrips (Costa and Robb, 1999). The color visual sensitivity of western flower thrips, or why they seem to be attracted to certain colors, is not well documented. The relative reflectance of UV wavelengths is important in determining whether western flower thrips will feed on a host plant (Vernon and Gillespie, 1990).

Visible and near infrared reflectance spectra were measured to determine distinct spectral features that would explain the attraction of thrips species to flowers and colors of sticky traps. In this study, flower color did contribute to attractiveness of the western flower thrips, with wavelengths in the 500-700nm most attractive to thrips, whether it was a sticky pad or the actual flower (Blumthal, et al., 2005). Also spectra measurements have shown that that a highly reflective UV surface is repellent to thrips and interfered with its host-seeking behavior in the 350-390nm range and more specifically in the 350-370nm range (Lewis, 1997). Brown and Brown, 1992, stated that silver mulches can be an effective control in reducing TSWV. A study on tomatoes using different colored plastic mulches specifically manufactured to repel thrips was studied at Auburn

University. In this study the silver mulch showed lower thrips in the early season counts and lower thrips in the late season counts by flower. Late season analysis also showed that the UV-reflective silver mulch reduced TSWV incidence compared to the other plastics used (Croxton, 2008). Thrips populations were lowest on aluminum mulch and whiteflies were lowest on yellow, aluminum, and orange mulches (Csizinsky et al., 1995). Also in studies by Stavisky et al., 2002, UV reflective mulches have been shown to reduce TSWV incidence by nearly 50%. Over a three year period, studies by Riley and Pappu (2004) reported that the use of reflective mulch, resistant plants and early season insecticides made a significant impact on thrips populations and TSWV infections and created considerable economic incentives. These results are beneficial in the search for the cure TSWV in tomatoes.

Spectrometric digital image color analysis of traps that were red, green, and blue, showed that blue sticky traps reflected considerably more light in the 400-500nm range, than the yellow sticky traps at 550-700nm. These results suggest that blue sticky traps are more effective in detecting the presence of thrips (Natwick, et al., 2007). Greenhouses covered with UV absorbing plastics have been shown to reduce thrips migration into greenhouses. Also the use of UV reflective surfaces around vents, doors and other entryways can reduce thrips migration into greenhouses (Costa and Robb, 1999).

Kemble et al, 2004 provided several recommendations to follow for the production of tomatoes. Tomatoes prefer a well drained, sandy clay loam, with a pH of 6.0 to 6.8. A recommendation for fertilizing tomatoes is 150 to 180 pounds of N/acre and

200 to 250 pounds of phosphorous (P_2O_5) and potash (K_2O) per acre (Kemble et al., 2004).

Tomatoes should be planted on raised beds 6 inches high and 30 to 36 inches wide that are covered with polyethylene plastic mulch. Polyethylene mulch will increase temperatures and in return increase growth rates and development. The polyethylene plastic conserves soil moisture and can reduce common problems such as soil compaction, fertilizer leaching, and weeds. Colored plastic mulches are also marketed and should be used depending on the season.

Drip irrigation in the form of drip tape or in-line tubing, is generally used underneath the plastic mulch in most commercial tomato production in the U.S. Tomatoes consist of approximately 85 to 95% water and need 0.5 to 1.5 inches of water per week (Kemble et al., 2004).

Tomatoes are grown from seed and then transplanted into the field with a spacing of 18 to 24 inches apart, with a row spacing of 4 to 5 feet (Kemble et al., 2004). Staking tomatoes with wooden stakes every other transplant will greatly improve fruit quality and yield. Tomato twine is used to tie one stake to the other down each side of the tomato plant, wrapping around each individual stake in each plot. This is usually done up to three times in one season depending on the plant height. Tying tomatoes as the season goes will make harvesting much easier (Kemble et al., 2004).

As seen by numerous studies no single control method exists to control thrips populations for plasticulture tomato production. Since both the colored mulches and Blue-X plastic growtubes have a high ultra-violet reflectance in the 350-370nm range, the objectives of my studies were: 1) to evaluate specifically manufactured colored mulches in reducing TSWV on field-grown tomatoes and 2) to evaluate the use of Blue-X growtubes that have a high ultra-violet reflectance in reducing thrips and TSWV in field-grown tomatoes. It was hypothesized that the colored mulches and the Blue-X growtubes would reduce thrips and TSWV incidence.

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CHAPTER II

EVALUATION OF SELECTED COLORED PLASTIC MULCH IN TOMATOES TO REDUCE THE INCIDENCE OF TOMATO SPOTTED WILT VIRUS

Abstract

A field study was conducted to evaluate the influence of colored mulch plastic on thrips ability to locate tomatoes (*Lycopersicon esculentum* Mill.). Mulch colors were selected based on ultra violet reflectance which has been shown to repel thrips. Specially manufactured colored mulches (Pliant Corp, Washington, GA) were: silver, red 1, red 2, black, and violet. Thrips population counts and plant yields were taken weekly. Enzyme-linked immunosorbent assay (ELISA) tests were completed early-season and mid-season to test for tomato spotted wilt virus (TSWV). Statistical anaylsis revealed that the colored mulches did effect thrips cup and flower counts, marketable weight, marketable count, and TSWV incidence. In cup counts of thrips the silver was consistently lower than all other treatments and black mulch had the highest cup count of thrips. In flower counts of thrips the silver mulch had the least thrips than any other treatment and the violet mulch had the highest count of thrips. Silver mulch had higher marketable weight and marketable fruit count then all other treatments followed by the violet mulch, but the violet mulch had less incidence of TSWV than the silver. The standard black mulch had the lowest marketable weight and marketable fruit count than all other treatments. In the later season test for TSWV, red 1 and violet similarly had the

lowest percentage of TSWV incidence and black had the highest percentage of TSWV incidence.

Introduction

Thrips were first described in 1744 by De Geer and were placed in the order Thysanoptera in 1836. To date there are more than 5,000 species of thrips recognized and placed into two suborders and eight families (Lewis, 1997a). Thrips occur worldwide, but are more commonly found in temperate and tropical areas of the globe. Thrips have very small slender bodies ≤1 mm long, are poor flyers with delicately fringed wings, long cilia, and vary in color depending on their stage of development (Zitter and Daughtrey, 1989). Thrips feed on plant material using piercing and sucking mouthparts on the leaves and the flowers of host plants. In order to feed, thrips pierce plant cells with a mandible stylet to create an entry hole into the plant, after which the c-shaped maxillary stylets join together to form a tube, which enters the cell to suck out the contents (Lewis, 1997b). Feeding of thrips causes damage that leads to discoloration, deformities, and reduced marketability of the crop. Thrips are known to cause economic damage to many crops including cabbage, cotton, onion, tomato, pepper, peanut, and tobacco. Thrips damage can be caused directly by thrips feeding, or indirectly by transmission of plant viruses (Morsello et al., 2008).

Western flower thrips, (*Frankliniella occidentalis* (Pergande)), damage plants by feeding on leaves and flowers and vectoring tospoviruses such as: impatient necrotic spot virus (INSP), and tomato spotted wilt virus (TSWV) (Blumthal et al., 2005). Western flower thrips not only spread TSWV and INSV they also serve as a virus host. Young tomato plants infected with TSWV results in lower yield and a higher percentage of damaged fruit than plants that are infected later in the growing season (Joost and Riley, 2008).

Thrips can only acquire TSWV in the larval stage where the virus inoculates for 3-10 days before transmission can occur (Zitter and Daughtrey, 1989). Once thrips become infected with TSWV they can transmit the virus for the remainder of their life. Western flower thrips cause tomato growers in the southeast the greatest economic loss.

Western flower thrips have many biological characteristics making control extremely difficult. The first larval stage of the western flower thrips only lasts 1-2 days, and then a second larval stage lasts 24 days. In this second stage, thrips are feeding and are capable of transmitting the viruses. At the end of the second larval stage, the insect stops feeding and moves into the soil or leaf litter to pupate. The insect goes through a prepupal stage (1-2 days) and pupal stage (1-3 days) before becoming an adult. Adult thrips can survive 30-45 days and lay 150-300 eggs each (Zitter and Daughtrey, 1989).

TSWV was originally described in Australia in 1919. Eight species of thrips in two genera, *Frankliniella* and *Thrips*, are reported to transmit TSWV and are known to infect more than 1,000 plant species (Joost and Riley, 2008). TSWV is the most important of the viruses transmitted by thrips. TSWV is the only member of an RNA-containing virus group that has membrane-bound spherical particles 70-90nm in diameter (Zitter and Daughtrey, 1989).

The primary spread of TSWV is from adult thrips that are carriers of the virus to the crop from sources such as weed hosts. Weed hosts should be eliminated in controlling thrips population because they serve as a reservoir for TSWV (Zitter and Daughtrey, 1989). Secondary spread usually occurs by thrips colonizing and reproducing on the current seasons crop or nearby weed hosts. Limited secondary spread of TSWV occurs within tomato and pepper fields with primary spread the most significant (Momol et al. 2004).

Symptoms of TSWV will vary in the tomato plant depending on the stage of infection. Some host plants of TSWV will develop symptoms within 5 days of being infected. Symptoms will appear visually on leaves, petioles, stems, and fruit. Symptoms on tomatoes appear in the form of yellow or brown ringspots on the fruit, brown streaks on the petioles or stem, stunted growth, necrotic leaf spots, tip dieback, premature fruit ripening, and one sided growth (Zitter and Daughtrey, 1989).

To specifically identify TSWV, special laboratory tests are required. An ELISA (enzyme-linked immunosorbent assay) is a serological test most commonly used. The ELISA test is the most accurate of all tests for TSWV (Zitter and Daughtrey, 1989).

Multiple control tactics for thrips and TSWV management have been simultaneously evaluated. To understand the epidemiology of TSWV it is important to understand the relationship between the vector, virus, and weed hosts. Several different management practices have been studied for controlling thrips, these including insecticide treatments, horticulture oils and insecticidal soaps, planting times of the host plant, host plant resistance, colored traps, predatory mites, and colored mulch.

In order for insecticide treatments to be beneficial, early detection of a thrips population is crucial. Chemical control involves many important steps such as selecting proper insecticides, frequency of applications, researching for the best application method, and having a pesticide rotation plan (Zitter and Daughtrey, 1989). The most widely used insecticide program for thrips consists of broad-spectrum insecticides. Imidacloprid and spinosad are the two most commonly used insecticides for thrips control. Application of imidacloprid on tomato transplants may offer some protection, but not complete control of the thrips population (Riley and Pappu, 2000). With so few insecticides available to control thrips, rotating insecticide chemicals is important in order to delay insecticide resistance. Excessive insecticide use, in conjunction with multiple insect generations per year, increases the possibility of insect populations developing resistance to specific insecticides (Immaraju et al., 1992).

Planting date was shown by Riley and Pappu, (2000) to have an effect on TSWV incidence in South Georgia. The later planted tomatoes resulted in higher TSWV incidence, lower thrips numbers, and lower tomato yields both in fruit quality and marketability. Early plantings on black plastic with an intensive insecticide treatment resulted in the highest yield (Riley and Pappu, 2000). However, Croxton (2008) observed anecdotally that early planted tomatoes in central Alabama were higher in TSWV incidence than later planted tomatoes. This conflicts with Riley and Pappu (2000) results that showed that earlier planted tomatoes had less TSWV incidence than later planted tomatoes. Riley and Pappu (2000) showed that even though the late planting date avoided thrips, it did not avoid transmission of TSWV. The overall percentage of TSWV-positive was no different between symptomatic and asymptomatic plants at harvest (Riley and Pappu, 2000). Furthermore, Culbreath et al., (2003) reported that no single management tool provides adequate control and resistant varieties are the most important factor in reducing incidence of TSWV.

In 2000, TSWV-resistant tomatoes by BHN Research Inc were released. These resistant varieties were ‘BHN-444’, ‘BHN-555’, and ‘BHN-640.’ The creation of these resistant varieties was successful; however the resistant variety is not appealing in taste (Riley and Pappu, 2004).

Many studies have been conducted on the trapping of thrips. Factors that influence the efficiency of thrips traps include color of traps, trap orientation, height of trap above the crop, color around the trap, and volatile chemicals to traps. The use of traps for western flower thrips with p-anisaldehyde has been reported to be helpful in early season monitoring (Teulon et al., 1993).

Neoseiulus cucumeris is a predacious mite used in studies at an application rate of 53 mites/m^2/week. Studies have shown that predatory mites alone do not have a strong enough impact on thrips populations for management (Van Driesche, et al. 2005).

Decoteau et al., (1997) have studied the manipulation of light environments to regulate chrysanthemum development using spectral plastics at Clemson University in South Carolina. Wilson and Rajapakse (2001) studied *Eustoma grandiflora* (Lisianthus) to measure plant response to photo selective plastic films with varying spectral transmission properties.

Certain species of insects have been shown to depend on UV light to orient themselves during flight and also recognize host plants. Studies suggest that thrips vary in their color preference, but are usually more attracted to light colors. Also highly reflective surfaces repel most thrips (Costa and Robb, 1999). The color visual sensitivity of western flower thrips, or why they seem to be attracted to certain colors, is not well documented. The relative reflectance of UV wavelengths is important in determining whether western flower thrips will feed on a host plant (Vernon and Gillespie, 1990).

Visible and near infrared reflectance spectra were measured to determine distinct spectral features that would explain the attraction of thrips species to flowers and colors of sticky traps. In this study, flower color did contribute to attractiveness of the western flower thrips, with wavelengths in the 500-700nm most attractive to thrips, whether it was a sticky pad or the actual flower (Blumthal, et al., 2005). Also spectra measurements have shown that that a highly reflective UV surface is repellent to thrips and interfered with its host-seeking behavior in the 350-390nm range and more specifically in the 350-370nm range (Lewis, 1997b). Brown and Brown, 1992, stated that silver mulches can be an effective control in reducing TSWV. A study on tomatoes using different colored plastic mulches specifically manufactured to repel thrips was studied at Auburn University. In this study the silver mulch showed lower thrips in the early season counts and lower thrips in the late season counts by flower. Late season analysis also showed that the UV-reflective silver mulch reduced TSWV incidence compared to the other plastics used (Croxton, 2008). Thrips populations were lowest on aluminum mulch and whiteflies were lowest on yellow, aluminum, and orange mulches (Csizinsky et al., 1995). Also in studies by Stavisky et al., 2002, UV reflective mulches have been shown to reduce TSWV incidence by nearly 50%. Over a three year period, studies by Riley and Pappu (2004) reported that the use of reflective mulch, resistant plants and early season insecticides made a significant impact on thrips populations and TSWV infections and created considerable economic incentives. These results are beneficial in the search for the cure TSWV in tomatoes.

Previous research as stated above has shown that reflective surfaces have shown the ability to repel thrips. Specially manufactured colored plastic was produced by Pliant Corp. (Washington, GA) (red 1, red 2, and violet) that was intended to have enhanced reflectance in the 350-370 nm range (Figure 1). Therefore, the objectives of this study was to determine the effect of the specially manufactured colored plastics along with silver and standard black mulch on the effect of thrips numbers, TSWV incidence and yields and grade of tomatoes.

Material and Methods

<u>Field Study</u>

Field studies were conducted in the summer of 2008 at the E.V. Smith Research Center (EVSRC), Auburn University, located in Shorter, AL (32.42N x 85.53W). The soil type at EVSRC is a marvyn sandy loam (fine-loamy, kaolinitic, thermic type Kanhapludults). ‘Florida 47’ tomatoes were seeded into Canadian Growing Mix 2 (Conrad Fafard Inc., Agawan, MA) in 72-cell flats at the Plant Sciences Research Center (PSRC) five weeks prior to transplanting and were grown according to recommended practices. Transplants were fertilized once a week with a 20N-4.4P-16.6K water soluble fertilizer (Peter’s Water Soluble Plant Food 20-10-20) (Scotts Co, Marysville, OH) at a rate of 265 mg/L of N. Transplants were hardened off the week before planting according to Kemble (2004). At EVSRC the soil was prepared and shaped into a series of six parallel beds 4 feet wide and approximately 100 yards in length. A preemergence herbicide was applied according to the label (Dual-Magnum, Sygenta Corp, Greensboro, NC) and no soil fumigation was used.

Treatments consisted of specially manufactured (Pliant Corp, Washington, GA) polyethylene plastic mulch (1.25 mil thickness, 5 feet wide) that were specifically formulated to contain a high percentage of ultraviolet reflectance in the 350-390 nm range. We measured seven different colors of formulated plastics using an Ocean Optics S2000 spectrometer (range 250-880 nm: Dunedin, Florida) coupled to a tungsten-deuterium light source. We used a bifurcated fiber-optic cable mounted in a metal probe that was placed at an angle of 90° to the plane of the colored plastic surface.

Color data were gathered as percent reflectance at 1 nm wavelength increments from 300 -700 nm and this output was processed using ColoR, version 1.5 (Montgomerie copyright 2002). Three series of readings were processed for each colored plastic that was received from Pliant Corporation.

Tomatoes were fertigated weekly with potassium nitrate (KNO_3) alternated with calcium nitrate ($Ca(NO_3)_2$) using drip tape with a Dosatron at a rate of 1:500 to 1:64 (ISO 9001, Clearwater, FL) fertilizer injector. Alternating the two fertilizers was done for the duration of the experiment and was scheduled according to Kemble (2004).

The specific treatments were: red 1, red 2, violet, black, and silver plastic mulches. Treatments were randomly assigned to a plot of 12 tomato plants in a randomized complete block design with four replications. Each replication consisted of three parallel rows and data were gathered from the center row to reduce variation.

Weekly thrips counts were gathered from each plant using the beat-cup method until first flower. Once the tomato plants began to flower, thrips counts were gathered by collecting ten open flowers from each plot and placing them in vials of alcohol (Riley and Pappu, 2004).

TSWV incidence (percent plants infected) was determined using a commercial enzyme-linked immunosorbent assay (ELISA) kit (Agdia, Inc., Elkhart, IN). The ELISA procedure was performed according to the manufacturer's instructions. TSWV incidence was determined two times during the season: 32 days after plants were transplanted to the field and 64 days after being transplanted. A single leaf sample from each plant, was taken from a terminal leaflet of a newly formed leaf. Then the sample was wrapped in a damp paper towel and placed on ice for transport to the laboratory. Each sample was processed for ELISA by grinding the leaf tissue using a motorized two roller press, leaf squeezing apparatus. General extraction buffer (2 ml) was added to the processed tissue (as per manufacturer's instructions). Tissue from known healthy control samples and a known positive control sample were added to each microtiter plate. Upon adding substrate, reactions were allowed to develop at room temperature for 60 to 90 minutes and recorded using a Sunrise microtiter plate reader (Phenix Research Products, Hayward, CA). A sample was considered positive for the presence of virus if the ELISA absorbance value was greater than the average plus three standard deviations of the negative control samples.

Data gathered from this study included cup and flower counts, marketable and non-marketable yields and TSWV incidence counts. Data were analyzed with the

GLIMMIX procedure of SAS (version 9.1; SAS Institute, Inc., Cary, NC) using generalized linear mixed model with the Poisson distribution and log link function, block as a random factor, and mulch color as the experimental factor. Data was analyzed separately for marketable, non-marketable (by individual collection date and using data from all corresponding collection dates as repeated measures) and by study location. Multiple-comparison-nonadjusted p values were obtained using the stimulation-stepdown method.

For the TSWV incidence counts an analysis of variance was performed on the data using SAS version 9.1.3 (SAS Institute, Cary, NC). Data were analyzed with PROC GENMOD using the binomial probability distribution. Differences in treatment least square means were determined using the DIFF option on the LSMEANS statement at $\alpha = 0.05$.

Results

The 2008 field study conducted at EVS revealed that colored mulches did affect thrips cup and flower counts, marketable weight, marketable fruit count, and TSWV incidence (Table 1 and Table 2). Thrips collected with cups in the early plant growth stage (before flowering) was affected by the treatments at the various collection dates and for the overall totals (Table 1). However, no clear trends were established in this study. Total overall thrips cup counts for plants with the silver mulch had lower thrips numbers than the plants with violet, black and red 1 mulches (Table 1). Plants grown with the black mulch conversely, had higher numbers of thrips compared to plants grown with the red 2 and silver.

The flower counts for thrips were more consistent in revealing differences for the treatments. Each week of sampling and the overall thrips flower counts revealed statistical differences (Table 1). Plants grown in the violet mulch had higher thrips flower counts than all treatments (Table 1).

TSWV incidence was not affected in the early season sampling (22 May) (Table 2). However, the later sampling (3 July) revealed some differences in TSWV incidence. Plants with the red 1 mulch (2.1% incidence) and violet mulch (4.1% incidence) had lower TSWV incidence compared to all others except the silver mulch (12.5% incidence).

Marketable weight was affected by the treatments (Table 2). Plants with the silver mulch had higher marketable weights than all other treatments. Marketable fruit counts were affected similarly by the silver mulch treatment with higher marketable fruit counts than all other treatments (Table 2). The standard black mulch was lower in marketable weights and fruit counts as compared to the violet and silver mulches (Table 2).

Discussion

In the colored mulch experiment at EVS our hypothesis was that the specially formulated plastics consisting of a high percentage of ultraviolet reflectance in the range of 350-390nm could potentially repel thrips and reduce TSWV. The most effective plastic mulch in this study in repelling thrips in cup and flower counts concluded to be silver which agrees with the research of others (Brown and Brown, 1992; Croxton, 2008; Csizinsky et al., 1995; Riley and Pappu, 2004; Stavisky et al., 2002). This study also showed that silver mulch produced double the yield of all other colored plastic mulch treatments. This is the first report of this increase in yield from silver mulch in tomato production. Even though silver did not reduce the incidence of TSWV in this study, the double production in marketable yield would still make it the best choice for producers over all other plastic mulches examined. The only downfall to silver is that it produces a glare that is bothersome to workers since it reflects all light.

The violet mulch (Figure 1) showed great potential to repel thrips with a reflective percentage from 20-50% in the 350-370 nm range in the three series of readings taken by the spectrometer. Also in the 350-370 range the percentage of reflectance continued to increase steadily indicating suitability for repelling thrips. The violet mulch did have the least incidence of TSWV of all other treatments, but similar to Red 1 mulch, even though it did not have a significant impact on lowering thrips counts during the growing season.

The color of the plastics did fade by the end of the project and the plastics began to breakdown from photodegredation which led to an increase in weeds which possibly had an effect on the ability of the mulches to deter thrips. The plastic colored mulch did however hold strong throughout the early season of this study when TSWV has the highest impact on growth and production. Further experiments with more durable plastic mulches would prove useful in evaluating the colored mulches effectiveness in repelling thrips and reducing the occurrence of TSWV. In future studies it would be helpful to collect temperature readings throughout the growing season. Higher temperatures may have been the result of less marketable fruit count in the other colored mulches due to increased temperature. Too high of temperatures could have caused early season flower drop which would have decreased yield. Overall colored plastic mulch still remains the most effective method in reducing thrips numbers and reducing the incidence of TSWV in tomato plants.

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Table 1. Thrips collected from cups and flowers in field grown tomatoes using five colors of plastic mulch, E.V. Smith Research Station, Shorter, AL, 2008.

	Thrips collected from cups (no.)					Thrips collected from flower (no.)						
Mulch Color	12 May	20 May	28 May	8 June	Overall[1]	6 June	16 June	23 June	30 June	10 July	16 July	Overall [1]
Red 1	14.50a	8.25ab	12.00ab	5.25a	40.00ba	21.00ab	6.50b	8.75a	14.25ab	5.50ab	17.00a	73.00b
Red 2	8.25a	9.50a	11.00b	3.00a	31.75bc	4.5b	9.50b	5.75ab	10.00ab	6.00ab	8.75bc	44.50c
Black	15.50a	8.00ab	25.00a	4.25a	52.75a	6.5b	5.75b	1.75b	3.50b	3.00bc	4.00c	24.50cd
Violet	16.50a	12.50a	10.75b	4.00a	43.75ba	30.25a	18.25a	9.25a	20.50a	8.00a	15.25ab	101.50a
Silver	7.25a	3.50b	1.50b	1.75a	14.00c	1.5b	6.00b	1.50b	3.50b	0.75c	1.25c	14.50d
Treatment effects	0.3694	0.0262	0.0245	0.6460	0.0117	0.0338	0.0263	0.0056	0.0355	0.0199	0.0034	<.0001

[1]Least square means from repeated measures analysis using counts from four and six collection dates (thrips collected from cups or flowers, respectively).

Table 2. Yield, grade, and TSWV incidence in field grown tomatoes using five colors of plastic mulch, E.V. Smith Research Station, Shorter, AL, 2008.

	YIELD				TSWV Incidence Counts3 and %2			
Mulch Color	Marketable weight	Non-marketable weight	Marketable count	Non-marketable count	5/22/2008		7/3/2008	
Red 1	21.51bc	15.23a	96.25bc	101.25a	0/47	0%a	1/47	2.1%c
Red 2	17.99bc	12.80a	86.00bc	98.00a	2/48	4.2%a	7/48	17.0%ab
Black	16.72c	12.12a	80.00c	85.00a	0/47	0%a	11/47	23.4%a
Violet	28.28b	17.81a	119.00b	116.75a	0/48	0%a	2/48	4.1%bc
Silver	44.28a	17.73a	184.25a	122.5a	1/48	2.0%a	6/48	12.5%abc
Treatment effects	.0008	.0996	.0005	.2542		.2721		.0071

[1]Least square means from repeated measures analysis from seven collection dates (weight in kg).

[2] Significance of pairwise comparisons are reported as unadjusted multiple-comparison p values obtained using the simulation-stepwise method.

[3] TSWV incidence analysis using the binomial probability distribution. Differences in treatment least square means were determined using the DIFF option on the LSMEANS statement at $\alpha = 0.05$.

Figure 1. Spectrometer reading of a specially formulated colored plastic mulch to show ultraviolet reflectance levels used on thrips ability to locate field grown tomatoes, 2008, E.V. Smith Research Station, Shorter, AL.

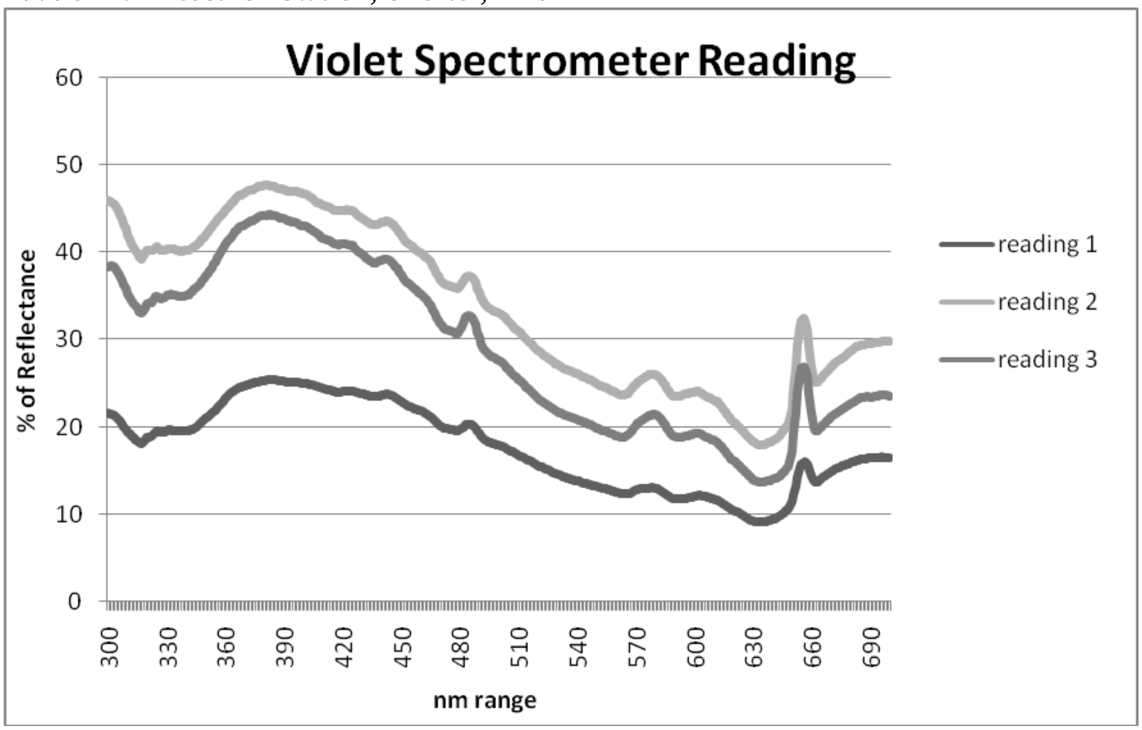


Figure 2. Effect of colored mulch on thrips ability to locate field grown tomatoes, 2008, E.V. Smith Research Station, Shorter, AL.

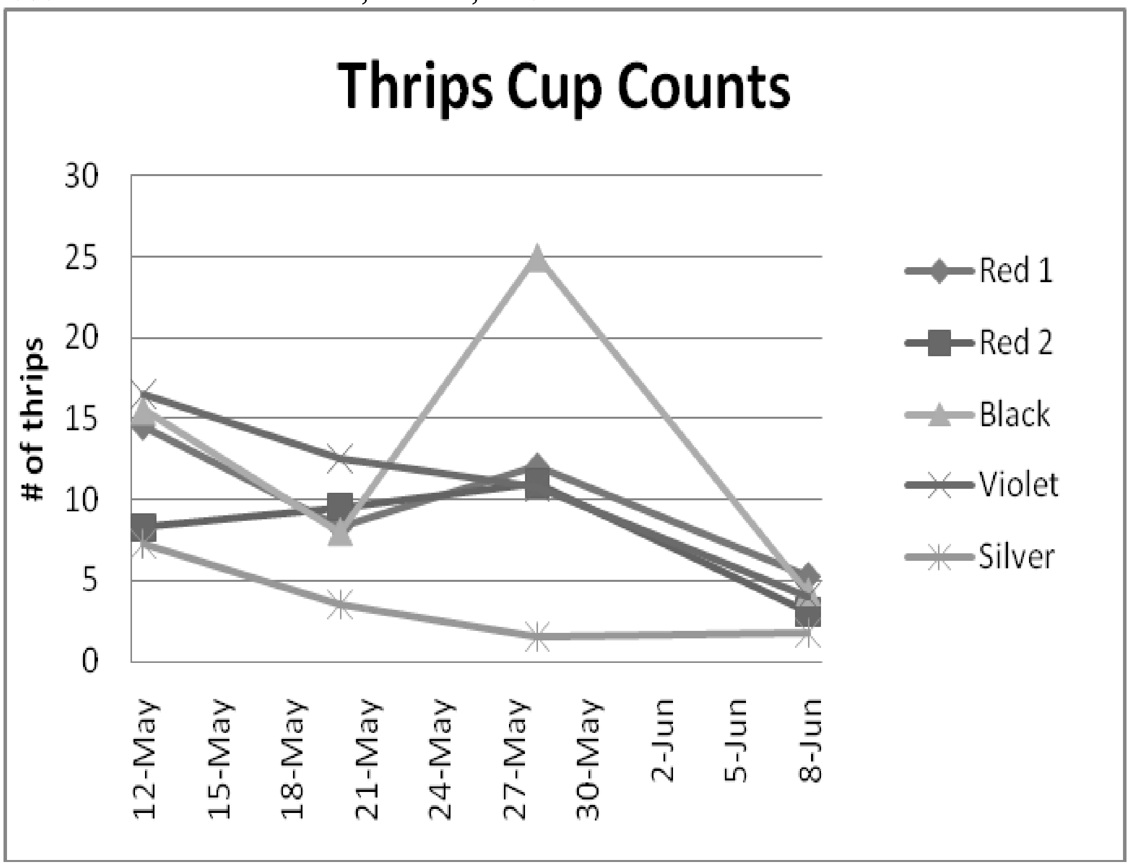
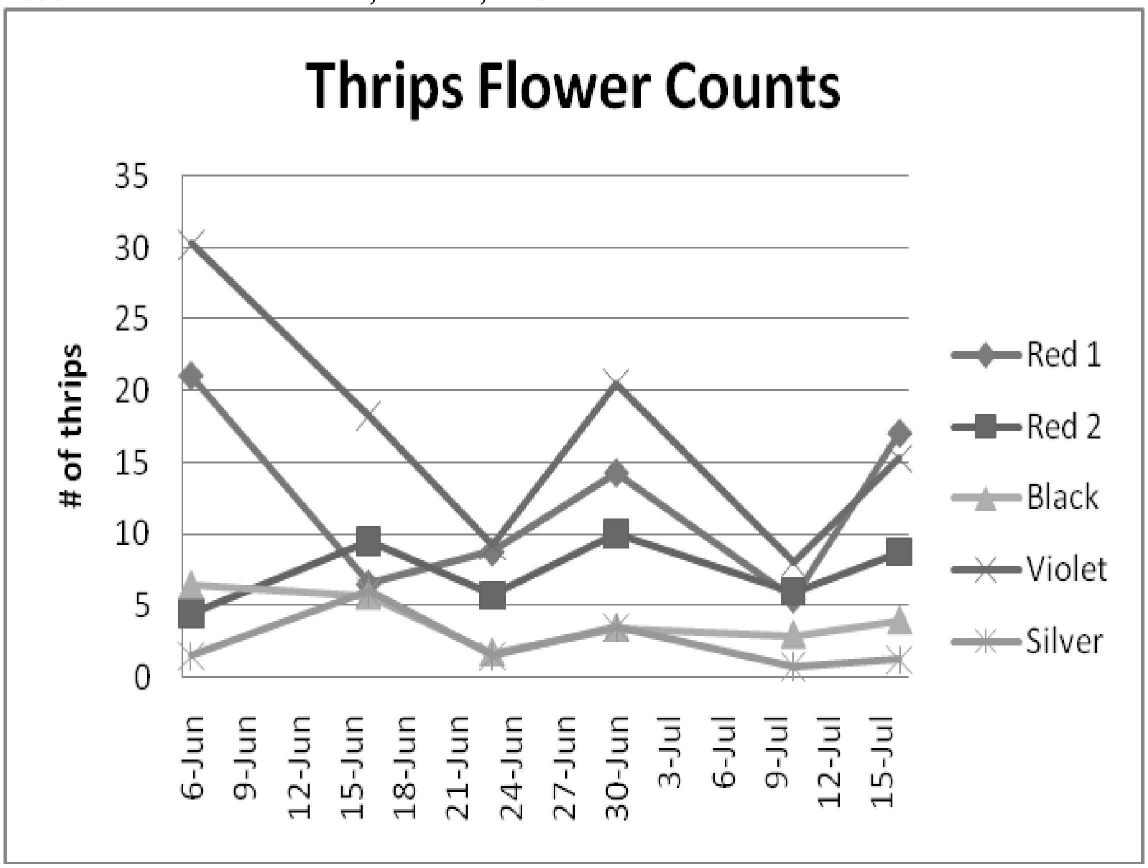


Figure 3. Effect of colored mulch on thrips ability to locate field grown tomatoes, 2008, E.V. Smith Research Station, Shorter, AL.



CHAPTER III

EVALUATION OF BLUE-X GROWTUBE SHELTERS TO REDUCE THRIPS AND TOMATO SPOTTED WILT VIRUS IN TOMATOES

Abstract

A field study was conducted to evaluate the influence of Blue-X Growtube Shelters on the ability of thrips to locate tomatoes (*Lycopersicon esculentum* Mill.). Growtube Shelters are manufactured by BLUE-X® Enterprises, Inc. in Sacramento, California and used in the nursery industry as grape shelters, tree shelters and direct seeding of native plants and shrubs. Blue-X Growtubes increase blue light which results in larger stem diameters and accelerated growth. This material was selected for this study based on its ultraviolet reflectance. The level of ultraviolet light reflectance that was measured on this material appeared beneficial in the search for a product to repel thrips. Varying tube sizes were selected for this study: 13”x9”, 13”x6”, 18”x9”, 18”x6”, and the non-treated control. Thrips population counts, height measurements, and plant yields were taken weekly. Enzyme-linked immunosorbent assay (ELISA) tests were completed early-season and mid-season to test for tomato spotted wilt virus (TSWV). Statistical anaylsis revealed that the Blue-X Growtubes did effect thrips counts measured by cup sampling as the counts were lower in the early season. No difference was seen in

the flower counts which were taken later in the season. The marketable weight, marketable counts were effected by the treatments. The control plot had the highest marketable weight and marketable count over the growtube treatments and the 18”x6” and 18”x9” had the lowest marketable weight and marketable fruit count. TSWV was highest in the early season ELISA test of the 18”x6” tubes than any other treatment. In the later testing date 13”x6” tubes had the highest amount of TSWV incidence of any other treatment (Table 4). Plant height was effected by the treatments. All growtube treatments had higher plant height than the control plots.

Introduction

Thrips are in the order Thysanoptera and were first described in 1744 by De Geer and placed in the order Thysanoptera in 1836. To date there are more than 5,000 species of thrips recognized and placed into two suborders and eight families. Of these 5,000 species, very few are recognized as serious crop pests (Lewis, 1997a).

Thrips have very small slender bodies $\leq$1 mm long, and are poor flyers with delicately fringed wings and long cilia. Thrips vary in color from straw-yellow to brown, with the variation being due to stage of development (Zitter and Daughtrey, 1989). Thrips feed on plant material using piercing and sucking mouthparts on the leaves and the flowers of host plants. Thrips pierce plant cells with a mandible stylet to create an entry hole into the plant, after which the c-shaped maxillary stylets join together to form a tube, which enters the cell to suck out the contents (Lewis, 1997b). Feeding of thrips causes damage that leads to discoloration, deformities, and reduced marketability of the crop. Thrips are known to cause economic damage to many crops including cabbage, cotton, onion, tomato, pepper, peanut, and tobacco. Thrips damage can be caused directly by thrips feeding, or indirectly by transmission of plant viruses (Morsello et al., 2008).

A type of thrips, *Frankliniella occidentalis*, western flower thrips, is found in the United States, Mexico, Europe, and Canada. This thrips species damages plants by feeding on leaves and flowers and vectoring tospoviruses such as: impatient necrotic spot virus (INSP), and tomato spotted wilt virus (TSWV) (Blumthal, et al., 2005).

Western flower thrips not only spread TSWV and INSV, they also serve as a virus host. Western flower thrips and tobacco thrips are vectors of TSWV which can damage the foliage of pre-flowering tomatoes (<8 wk old). Young tomato plants infected with TSWV results in lower yield and a higher percentage of damaged fruit than plants that are infected later in the growing season (Joost and Riley, 2008).

TSWV is the most important of the viruses transmitted by thrips. TSWV is the only member of an RNA-containing virus group that has membrane-bound spherical particles 70-90mm in diameter (Zitter and Duaghtrey, 1989). TSWV was originally described in Australia in 1919 and is known to infect more than 1,000 plant species (Joost and Riley, 2008). The primary spread of TSWV is from adult thrips that are carriers of the virus to the crop from sources such as weed hosts. Weed hosts should be eliminated in controlling thrips population because they serve as a reservoir for TSWV (Zitter and Daughtrey, 1989).

Symptoms of TSWV will vary in the tomato plant depending on the stage of infection. Some host plants of TSWV will develop symptoms within 5 days of being infected. Symptoms will appear visually on leaves, petioles, stems, and fruit. Symptoms on tomatoes appear in the form of yellow or brown ringspots on the fruit, brown streaks on the petioles or stem, stunted growth, necrotic leaf spots, tip dieback, premature fruit ripening, and one sided growth (Zitter and Daughtrey, 1989). To specifically identify TSWV, special laboratory tests are required. An ELISA (enzyme-linked immunosorbent assay) is a serological test most commonly used. The ELISA test is the most accurate of all tests for TSWV.

Western flower thrips have many biological characteristics making control extremely difficult. The first larval stage of the western flower thrips only lasts 1-2 days, and then a second larval stage lasts 24 days. In this second stage, thrips are feeding and are capable of transmitting the viruses. At the end of the second larval stage, the insect stops feeding and moves into the soil or leaf litter to pupate. The insect then goes through a prepupal stage (1-2 days) and pupal stage (1-3 days) before becoming an adult. Adult thrips can survive 30-45 days and lay 150-300 eggs each. Western flower thrips feed mainly on flowers and plant terminals where they are protected, which makes control even more difficult (Zitter and Daughtrey, 1989).

Taking accurate counts of thrips populations is important for research purposes and reducing variability within a study. The most commonly used and most accurate methods in counting thrips are the aspirator and the beat-cup method. The beat-cup method was studied in 2000 in comparison to other collecting methods and proved to be the most precise in counts of thrips populations (Joost and Riley, 2004).

Plants contain different pigments including chlorophyll, carotene, and xanthophylls, which can respond to different wavelengths of light. Light of different wavelengths can have different effects on plant growth. Most plants responses are regulated by red and blue light. Blue light also triggers a phototropic response and green light has a negative effect on plant growth. Plants are able to detect even a slight change in light composition through their photoreceptors. Light quality is mainly sensed by the presence of different light receptors specific for different wavelengths. Photoreceptors function as signal transducers to provide information that controls physiological and morphological responses (Rajapakse et al., 1999).

Decoteau et al., (1997) have studied the manipulation of light environments to regulate chrysanthemum development using spectral plastics at Clemson University in South Carolina. Wilson and Rajapakse (2001a) studied *Eustoma grandiflora* (Lisianthus) to measure plant response to photo selective plastic films with varying spectral transmission properties. Plant response to photo selective plastic films with varying spectral distribution properties was also studied using three sub-tropical perennials (Wilson and Rajapaske, 2001b).

Tree shelters are tubes made of a translucent polypropylene film, which is placed around tree seedlings or transplants at planting time (Burger et al., 1992). Tree shelters increase temperature, humidity, and CO_2 concentrations which are believed to cause increased growth in trees. The quick establishment of small trees results in lower costs (Svihra et al., 1993). The use of plastic tree shelters for low cost establishment of street trees showed that height and caliper of all the tree species that were tested equaled or exceeded trees those without the tree shelters (Jones et al., 1996). Tree shelters bring the greatest impact to tree seedlings and transplants in the first two years, then the shelters should be removed (Gerhold, 1999).

Blue-X growtube shelters (BLUE-X® Enterprises, Inc., Sacramento, California) are used in the nursery industry as grape shelters, tree shelters and with direct seeding.

Blue-X shelters enable plants to make full use of nature's beneficial blue light to increase stem diameter and to accelerated growth. Blue-X shelters create a beneficial microclimate within the shelter with higher temperatures and humidity levels (Frearson and Weiss, 1987). Shelters consistently increase survival rates and growth rates, but effects can differ among species (Potter, 1991). Shelters are thought to increase the height and diameter of trees in less time due the ability to increase the length of the growing season (Minter, et al., 1992). Tree shelters were evaluated as a means of accelerating height growth of tree-form crapemyrtles. These studies found that all plants grown in tree shelters flowered later than unsheltered plants and appear to have straighter, more upright trunks with minimal lateral shoot development (Brooks, 2006). These shelters shorten production time in some cultivars by enhancing height growth or improving plant forms. Tree shelters have also been found to have a high level of ultraviolet reflectance within the plastic material. The spectrophotometer readings for the blue plastics revealed it as a good candidate for repelling thrips (Figure 4).

The level of ultra violet reflectance that was shown in the Blue-X Shelters shows promise of reducing TSWV and would be a suitable alternative to the silver mulches. In turn, the objective of this study was to evaluate Blue-X Shelters in reducing TSWV in field grown tomatoes. The stated hypothesis is that the selected shelters with ultra violet reflectance in the 300-700nm range will decrease thrips populations and the occurrence of TSWV in tomato production.

Materials and Methods

Field Studies

A field study was conducted in the summer of 2008 at the Old Agronomy Farm (OAF), Auburn University, Auburn, AL (32.609N x 85.48W). The soil type at OAF is a marvyn sandy loam (fine-loamy, kaolinitic, thermic type Kanhapludults). 'Florida 47' tomatoes were seeded into Canadian Growing Mix 2 (Conrad Fafard Inc., Agawan, MA) in 72-cell flats at the Plant Sciences Research Center (PSRC) six weeks prior to transplanting and fertilized once a week with a 20N-4.4P-16.6K water soluble fertilizer (Peter's Water Soluble Plant Food 20-10-20) (Scotts Co, Marysville, OH) at a rate of 265 mg/L of N. The transplants were hardened off the week before planting according to Kemble (2004). At the OAF, the soil was prepared and shaped into a series of five parallel beds four feet wide and approximately 100 yards in length. A preemergence herbicide was applied according to the label (Dual-Magnum, Sygenta Corp, Greensboro, NC) and no soil fumigation was used.

Treatments consisted of Blue-X Growtube Shelters (BLUE-X Enterprises, Inc., Sacramento, CA) that were specially manufactured and modified to a larger size for each individual tomato plant in each treatment in this experiment. The shelters are made from a translucent polyproplene film. The treatments for this study were different sizes of these growtubes at a height and width of 13"x6", 13"x9", 18"x6", and 18"x9". Blue-X Growtubes were chosen for this study due to the high percentage of ultraviolet reflectance in the 350-390 nm range seen in this sleeve and insert when run through the spectrometer. We measured the outer sleeve and the inner plastic film of the growtubes using an Ocean Optics S2000 spectrometer (range 250-880 nm: Dunedin, Florida) coupled to a tungsten-deuterium light source. We used a bifurcated fiber-optic cable mounted in a metal probe that was placed at an angle of 90° to the plane of the plastic surface.

Tomatoes were fertigated weekly with potassium nitrate (KNO_3) alternated with calcium nitrate ($Ca(NO_3)_2$) using drip tape with a Dosatron at a rate of 1:500 to 1:64, (ISO 9001, Clearwater, FL) fertilizer injector. Alternating the two fertilizers was done for the duration of the experiment and was scheduled according to Kemble (2004).

The specific treatments consisted of different sizes of tubes that were placed around each tomato in each treatment two weeks after they were transplanted into the field. The specific treatments were: 13"x6", 13"x9", 18"x6", 18"x9", and the control. Treatments were randomly assigned to a plot of 12 tomato plants in a randomized complete block design with six replications. Weekly thrips counts were gathered from each plant using the beat-cup method until first flower. Once the tomato plants began to flower, thrips counts were gathered by collecting ten open flowers from each plot and placing them in vials of alcohol (Riley and Pappu, 2004).

TSWV incidence (percent plants infected) was determined using a commercial enzyme-linked immunosorbent assay (ELISA) kit (Agdia, Inc., Elkhart, IN). The ELISA procedure was performed according to the manufacturer's instructions. TSWV incidence was determined two times during the season: 30 days after plants were transplanted to the field and 63 days after being transplanted. A single leaf sample from each plant, consisting of a terminal leaflet of a newly formed leaf, was collected, wrapped in a damp paper towel and placed on ice for transport to the laboratory. Each sample was processed for ELISA by grinding the leaf tissue using a motorized two roller press, leaf squeezing apparatus. General extraction buffer (2 ml) was added to the processed leaf tissue (as per manufacturer's instructions). Tissue from known healthy control samples and a known positive control sample were added to each microtiter plate. Upon adding substrate, reactions were allowed to develop at room temperature for 60 to 90 minutes and recorded using a Sunrise microtiter plate reader (Phenix Research Products, Hayward, CA). A sample was considered positive for the presence of virus if the ELISA absorbance value was greater than the average plus three standard deviations of the negative control samples.

Data gathered from this study included cup and flower counts, marketable and non-marketable yields and TSWV incidence counts. Data were analyzed with the GLIMMIX procedure of SAS (version 9.1; SAS Institute, Inc., Cary, NC) using generalized linear mixed model with the Poisson distribution and log link function, block as a random factor, and mulch color as the experimental factor. Data was analyzed separately for marketable, non-marketable (by individual collection date and using data from all corresponding collection dates as repeated measures) and by study location. Multiple-comparison-nonadjusted p values were obtained using the stimulation-stepdown method.

For the TSWV incidence counts, an analysis of variance was performed on the data using SAS version 9.1.3 (SAS Institute, Cary, NC). Data were analyzed with PROC GENMOD using the binomial probability distribution. Differences in treatment least square means were determined using the DIFF option on the LSMEANS statement at $\alpha = 0.05$.

Results

Statistical anaylsis revealed that the Blue-X growtubes did affect thrips populations (Table 3). Thrips counts measured by cups were lower in the early season (Table 3) (Figure 5). The 18"x9" and the 18"x6" growtube treatments were lower in thrips cup counts than the control for the first and second sampling date (29 May and 5 June) as well as the overall cup counts (Table 3). In addition, the 18"x9" and the 18"x6" treatments had lower thrips cup counts than the 13"x6" on 29 May and the overall counts (Table 3).

No difference was seen in the flower counts which were taken later in the season (Table 3) (Figure 6). The marketable weight, marketable fruit counts were affected by the treatments. The control plots had the highest marketable weight and marketable fruit count over the growtube treatments except the 13"x9" treatments which were similar (Table 4). The 18"x9" treatments had lower marketable weight and marketable fruit count compared to all other treatments except the 18"x6" treatments (Table 4).

When the data was analyzed for yield and grade by early, mid and late-season some differences were observed. The control plots had higher marketable yields than all other treatments for the early-season harvest. In addition, the control plots had higher marketable fruit counts than the 18"x6" and 18"x9" treatments (Table 5). The mid-season data did not show any differences. The late-season data showed that the 18"x9" growtube treatment had the highest marketable weight and marketable fruit count compared to the control and the 13"x6" treatments (Table 5).

TSWV was highest in the early season ELISA test for the 18"x6" tubes than any other treatment except the 13"x6" tubes (Table 4). In the later season testing date the

13”x6” tubes had higher incidence of TSWV than the 18”x9” and the controls, but it was similar to the 13”x9” and the 18”x6” treatments (Table 4). Plant height was affected by the treatments. All tube treatments outgrew the control plots in all measurements recorded (Table 6) (Figure 7). In the measurements for (26 June and 3 July) 13”x6” and the 13”x9” tubes were shorter than the 18”x6” and the 18”x9” tubes (Table 6) (Figure 7).

Discussion

In the study using Blue-X Growtube shelters around tomato plants our hypothesis was that the growtube shelters would create a barrier to the plant as well as a high level of ultraviolet reflectance in the 350-390 nm range which could potentially repel thrips and reduce TSWV. The plastic sleeve and the plastic clear blue tinted insert together (Figure 4) had a reflective percentage from 45-70% in the 350-370 nm range in the three series of readings taken by the spectrometer. Also in the 350-370 range the percentage of reflectance continued to increase indicating suitability for repelling thrips.

Results from this study concluded that the 18”x9” growtubes had the lowest thrips in the cup counts, but had the highest TSWV incidence counts in the later testing. The cup count numbers decreased drastically into the summer months. This agrees with research that thrips move from the vegetation to flowers as the season continues (Joost and Riley, 2008). No difference was seen in flower counts. The control treatments had higher marketable yield than any other treatment. In the height measurements, all of the growtube treatments drastically outgrew the controls.

We concur that due to the continuous vegetative growth this caused a delay in fruiting for the tube treatments. Further research should be done in the use of growtubes for earlier plantings of tomatoes. The 13”x6” and 13”x9” tubes did not delay fruiting and kept thrips counts lower in the early season when tomatoes are most susceptible to TSWV. The growtube shelters could also make it possible to plant tomatoes earlier in the field due to the microclimate that is formed within the tube (Frearson and Weiss, 1987). In further research it would be beneficial to take temperature readings throughout the growing season inside the growtubes. More studies should be done using growtubes for home gardeners and in greenhouses and studying the possibilities of using indeterminant tomatoes in combination with growtubes to increase and prolong fruit production.

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Table 3. Thrips collected from cups and flowers in field grown tomatoes using five different treatments of Blue-X Growtubes, Plant Science Research Center, Auburn, AL, 2008.

	Thrips collected from cups (no.)				Thrips collected from flower (no.)					
Treatments	29 May	5 June	12 June	Overall[1]	16 June	23 June	30 June	10 July	16 July	Overall [1]
13x6	9.333b	3.500abc	0.833a	13.667b	3.000a	6.167ab	3.333a	6.667a	2.833ab	1.500a
13x9	5.500bc	2.500bcd	0.000a	8.000c	4.000a	5.500ab	4.667a	5.833a	4.333ab	2.000a
18x6	2.833c	1.500cd	.667a	5.000cd	4.333a	6.833ab	4.833a	8.333a	4.167ab	2.000a
18x9	1.833c	0.000d	.667a	2.500d	4.000a	8.167a	3.333a	5.167a	6.667a	2.333a
Control	15.167a	5.833a	.500a	21.500a	3.333a	3.500b	3.167a	5.167a	1.500b	1.167a
Treatment effects	<.0001	.0034	.5706	<.0001	.2351	.0586	.7751	.7911	.1261	.3471

[1]Least square means from repeated measures analysis using counts from four and six collection dates (thrips collected from cups or flowers, respectively).

Table 4. Yield, grade, and TSWV incidence in field grown tomatoes using five different treatments of Blue-X growtubes, Plant Science Research Center, Auburn, AL, 2008.

	YIELD[2]				TSWV Incidence Counts[3] and %[2]				
treatments	Marketable weight	Non-marketable weight	Marketable count	Non-marketable count		6/4/2008		7/7/2008	
13x6	10.270ab	2.056a	51.000ab	9.500a	13x 6	6/72	8.33%ab	17/72	23.6%a
13x9	9.922ab	3.147a	49.667ab	14.833a	13x 9	1/72	1.4%b	10/72	13.8%ab
18x6	6.240bc	2.472a	31.833bc	9.667a	18x 6	8/72	11.1%a	11/72	15.27%ab
18x9	5.750c	1.674a	28.833c	7.333a	18x 9	2/72	2.78 %b	4/70	5.7%bc
Control	12.946a	2.779a	69.000a	13.833a	Control	2/72	2.78%b	6/72	8.33%bc
Treatment effects	.0028	.1362	.0011	.1189		.0154		.0002	

[1]Least square means from repeated measures analysis from seven collection dates (weight in kg).

[2] Significance of pairwise comparisons are reported as unadjusted multiple-comparison p values obtained using the simulation-stepwise method.

[3] TSWV incidence analysis using the binomial probability distribution. Differences in treatment least square means were determined using the DIFF option on the LSMEANS statement at $\alpha = 0.05$.

Table 5. Yield and grade in field grown tomatoes using five different treatments of Blue-X Growtubes, Plant Science Research Center, Auburn, AL, 2008.

	YIELD								
	Early Season			Mid Season			Late Season		
treatments	Marketable weight	Marketable count	Non-Marketable weight	Marketable weight	Marketable count	Non-Marketable weight	Marketable weight	Marketable count	Non-Marketable weight
13x6	1.7633ab	9.11073ab	.27290ab	3.3416ab	19.000ab	.7170b	2.3383b	18.500c	1.6448a
13x9	1.9301ab	9.8552ab	.43573a	3.4284ab	19.500ab	.8368b	3.2579ab	25.667ab	1.68714a
18x6	1.0949bc	6.0619bc	.40107a	3.4793ab	19.333ab	.8038b	3.2333ab	24.667ab	1.7726a
18x9	.6548c	3.3977c	.11242b	3.2004b	17.667b	.7377b	3.8933a	29.333a	2.0969a
Control	2.3297a	13.3290a	.30703ab	4.7419a	26.667a	1.1511a	2.6458b	19.500bc	1.6040a
Treatment effects	.0022	.0012	.0446	.0949	.2299	.0224	.0271	.0157	.6566

[1]Least square means from repeated measures analysis from seven collection dates (weight in kg).

[2] Significance of pairwise comparisons are reported as unadjusted multiple-comparison p values obtained using the simulation-stepwise method.

Table 6. Height in (cm) and marketable grade in field grown tomatoes using five different treatments of Blue-X Growtubes, Plant Science Research Center, Auburn, AL, 2008.

	Height (cm)[1]				
Treatments	5 June	12 June	19 June	26 June	3 July
13x6	42.333a	55.833ab	65.042a	74.375b	77.292b
13x9	43.417a	59.083a	67.792a	72.833b	78.333b
18x6	48.875a	62.792a	71.167a	80.167a	86.125a
18x9	44.208a	61.583a	69.625a	80.542a	88.000a
Control	32.292b	46.250c	51.000b	56.458c	57.792c
Treatment effects	.0005	.0017	<.0001	<.0001	<.0001

[1]Least square means from repeated measures analysis from five collection dates.

Figure 4. Spectrometer reading of Blue-X Growtube Shelters to show ultraviolet reflectance levels used on thrips ability to locate field grown tomatoes, 2008, Plant Science Research Center, Auburn, AL.

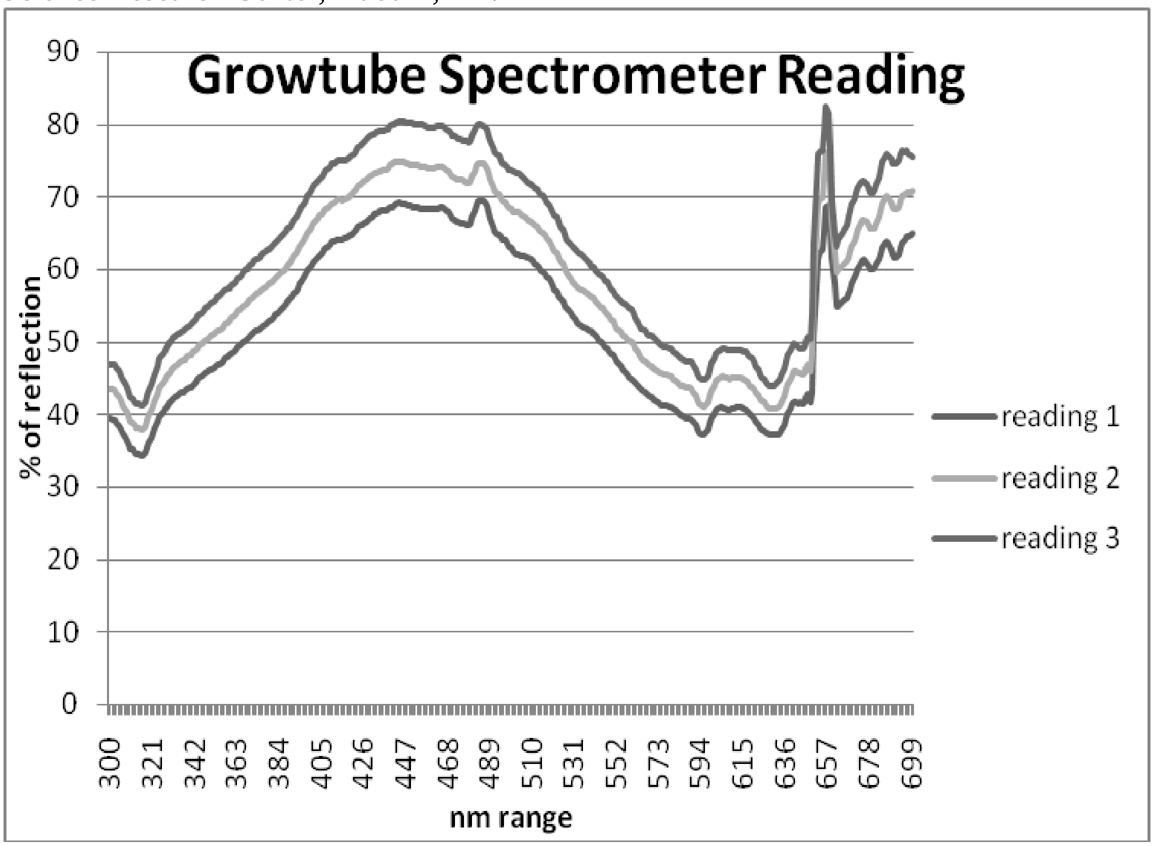


Figure 5. Effect of Blue-X Growtubes on thrips ability to locate field grown tomatoes, 2008, Plant Science Research Center, Auburn, AL.

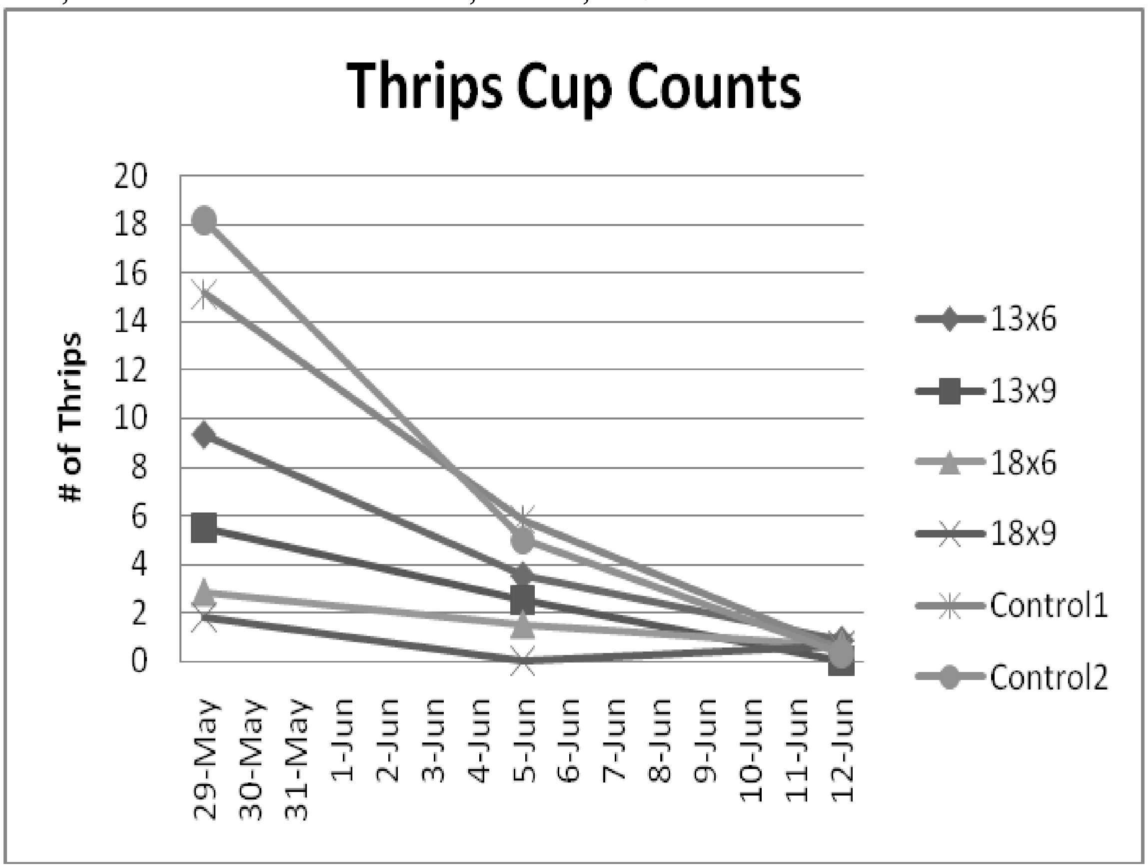


Figure 6. Effect of Blue-X Growtubes on thrips ability to locate field grown tomatoes, 2008, Plant Science Research Center, Auburn, AL.

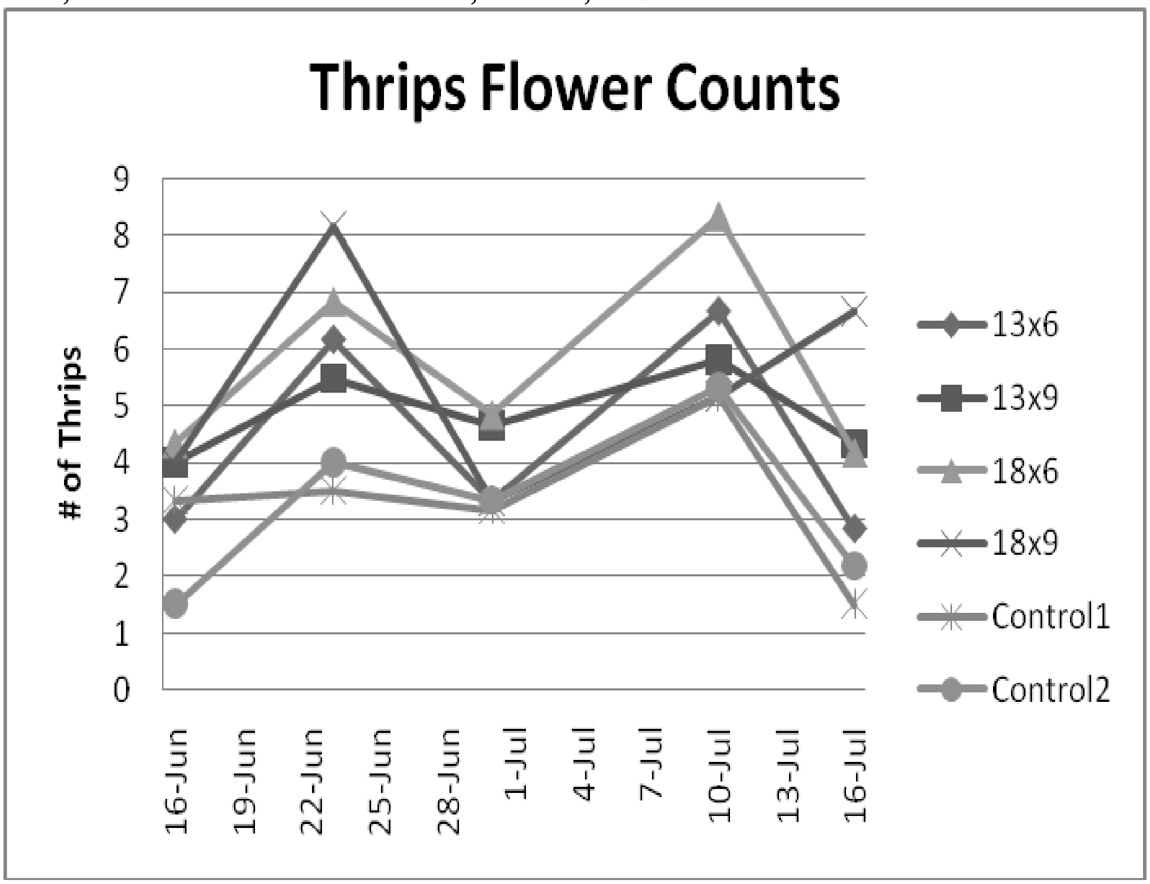
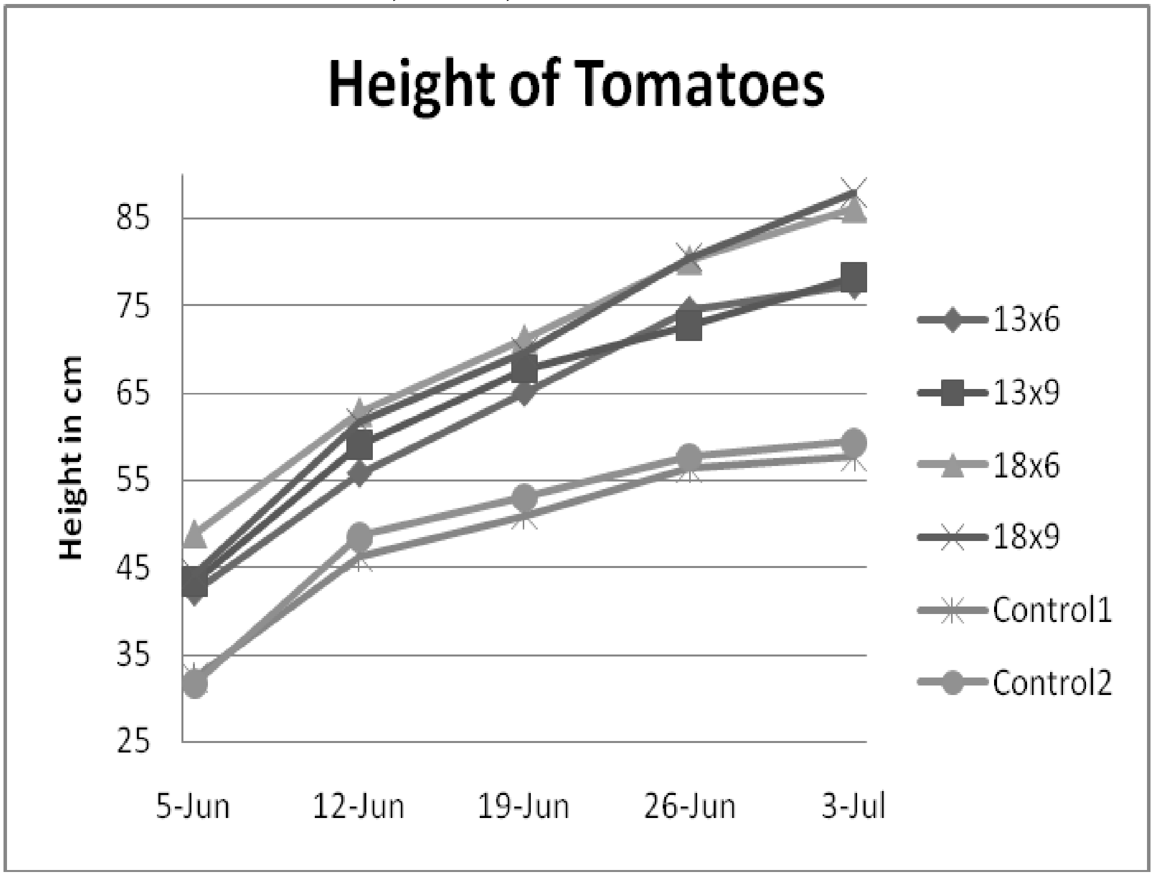


Figure 7. Effect of Blue-X Growtubes on plant height of field grown tomatoes, 2008, Plant Science Research Center, Auburn, AL.



CHAPTER IV

FINAL DISCUSSION

Thrips have become the focus of many commercial growers as well as small scale gardeners as the tomato spotted wilt virus (TWSV) continues to cause losses in production and profits. As a result this vector and the virus it transmits has become the focus of much study and research. Prior to these experiments researchers have been using colored plastic mulches to repel thrips, but very few promising results have occurred. Prior to these experiments Blue-X growtube shelters have never been studied in relation to tomato production or tomato research.

In the colored mulch experiment at EVS our hypothesis was that the specially formulated plastics consisting of a high percentage of ultraviolet reflectance in the range of 350-390nm could potentially repel thrips and reduce TSWV. The most effective plastic mulch in this study in repelling thrips in cup and flower counts concluded to be silver which agrees with the research of others (Brown and Brown, 1992; Croxton, 2008; Csizinsky et al., 1995; Riley and Pappu, 2004; Stavisky et al., 2002). This study also showed that silver mulch produced double the yield of all other colored plastic mulch treatments. This is the first report of this increase in yield from silver mulch in tomato production. Even though silver did not reduce the incidence of TSWV in this study, the double production in marketable yield would still make it the best choice for producers over all other plastic mulches examined. The only downfall to silver is that it produces a glare that is bothersome to workers since it reflects all light.

The violet mulch (Figure 1) showed great potential to repel thrips with a reflective percentage from 20-50% in the 350-370 nm range in the three series of readings taken by the spectrometer. Also in the 350-370 nm range the percentage of reflectance continued to increase steadily indicating suitability for repelling thrips. The violet mulch did have the least incidence of TSWV of all other treatments, but similar to Red 1 mulch, even though it did not have a significant impact on lowering thrips counts during the growing season.

The color of the plastics did fade by the end of the project and the plastics began to breakdown from photodegredation which led to an increase in weeds which possibly had an effect on the ability of the mulches to deter thrips. The plastic colored mulch did however hold strong throughout the early season of this study when TSWV has the highest impact on growth and production. Further experiments with more durable plastic mulches would prove useful in evaluating the colored mulches effectiveness in repelling thrips and reducing the occurrence of TSWV.

In future studies it would be helpful to collect temperature readings throughout the growing season. Higher temperatures may have been the result of less marketable fruit count in the other colored mulch treatments due to increased temperature. Too high of temperatures could have caused early season flower drop which would decrease yields. Overall colored plastic mulch still remains the most effective method in reducing thrips numbers and reducing the incidence of TSWV in tomato plants.

In the study using Blue-X Growtube shelters around tomato plants our hypothesis was that the growtube shelters would create a barrier to the plant as well as a high level of ultraviolet reflectance in the 350-390 nm range which could potentially repel thrips and reduce TSWV. Results from this study concluded that the 18”x9” growtubes had the lowest thrips in the cup counts, but had the highest TSWV incidence counts in the later testing. No difference was seen in flower counts. The control treatments had higher marketable yield than any other treatment. We concur that due to the continuous vegetative growth this caused a delay in fruiting for the tube treatments. The cup count numbers decreased drastically into the summer months. This agrees with research that thrips move from the vegetation to flowers as the season continues (Joost and Riley, 2008). In the height measurements, all of the growtube treatments drastically outgrew the controls.

Further research should be done in the use of growtubes for earlier plantings of tomatoes. The 13”x6” and 13”x9” tubes did not delay fruiting and kept thrips counts lower in the early season when tomatoes are most susceptible to TSWV. The growtube shelters could also make it possible to plant tomatoes earlier in the field due to the microclimate that is formed within the tube (Frearson and Weiss, 1987). In further research it would be beneficial to take temperature readings throughout the growing season inside the growtubes. More studies should be done using growtubes for home gardeners and in greenhouses and studying the possibilities of using indeterminant tomatoes in combination with growtubes to increase and prolong fruit production.

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