ABSTRACT

SPIVEY, TODD ALAN. Management and Control of Thrips (Thysanoptera: Thripidae) Populations on Cotton Through Current and Novel Insecticidal Applications and Timing of Cotton Planting in the Upper Southeast. (Under the direction of Dr. Keith Edmisten).

Thrips in the upper Southeast can be devastating to cotton growers and their crop. The thrips complex can be North Carolina's most economically damaging insect pest complex. Thrips can cause severe damage to cotton seedlings potentially leading to significant yield loss and maturity delay. Therefore, research examining management and control of thrips populations benefits growers across the Cotton Belt, especially those growing in the upper Southeast. Field trials were conducted in 2012 and 2013 in various locations across eastern North Carolina to evaluate routine and novel thrips control methods. Thrips control methods evaluated included in-furrow and foliar insecticidal applications, insecticidal seed treatments, and variations in cotton planting dates.

Imidacloprid, a neonicotinoid insecticide, applied as a stream of finished product in-furrow with treated seed was tested as a novel method of managing thrips populations in on farm trials in Wilson, NC in 2012 and 2013. Thrips abundance and yield data suggest that using this specific method of in-furrow application with a seed treatment will not only reduce thrips abundance throughout the cotton seedling stage, but will increase yields, particularly in years when growing conditions are not conducive for plants to compensate for early season thrips damage and stresses. Imidacloprid applied in-furrow with a seed treatment reduced thrips densities and increased lint yield compared to the commercial thiamethoxam seed treatment alone as well as the untreated check.

In tests conducted at the Upper Coastal Plain Research Station near Rocky Mount, NC, screening tests of insecticidal methods for controlling thrips populations were conducted in 2012 and 2013 to compare commonly-recommended and novel control practices. Insecticidal seed treatments and insecticides sprayed into the open furrow were compared, most of which were included with and without a follow up foliar application applied approximately 3 weeks after planting. Commercially available seed treatments, Avicta Complete, Acceleron N, and Poncho/VOTiVO/Aeris all provided limited control of thrips and required a follow up foliar application. A commercially unavailable, approximately 8x rate (3 mg/seed) of imidacloprid treated seed consistently reduced thrips compared to the above standard seed treatment rates. Though several treatments performed well in reducing thrips abundance compared to the untreated check, only the 8x rate of imidacloprid seed treatment at 3 mg per seed increased lint yield, although it did so at only one of four site-years.

The third field experiment evaluated the impact of planting date and two insecticide control treatments on thrips populations. The recommended planting date generally had the highest thrips abundance regardless of insecticide treatments. The early and late planting dates had fewer thrips than plots planted according to extension recommendations. Though thrips abundance was greater on the recommended planting date, yields were also greatest on the recommended planted plots due to optimization of planting date and season length.

The goal of all growers is to increase yields without increasing costs associated with producing high yielding crops. This research gives growers the ability to understand different proven methods of thrips control. The approaches evaluated in this research and ability of the methods to reduce thrips and increase yield are important, especially in years when growing conditions are not conducive to cotton's ability to compensate for early season thrips damage to cotton seedlings.

Management and Control of Thrips (Thysanoptera: Thripidae) Populations on Cotton Through Current and Novel Insecticidal Applications and Timing of Cotton Planting in the Upper Southeast

by
Todd Alan Spivey

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APPROVED BY:

Jack Bacheler

Dominic Reisig

Keith Edmisten
Chair of Advisory Committee

DEDICATION

This thesis is dedicated to my grandfather, Rev. Berry Barbour, and to the memory of my grandparents, Dixie Barbour and J. Lester and Jean Spivey. I also dedicate this thesis to my parents, Rex and Debbie Spivey, my brother, Matthew Spivey, and to my future wife, Cortney Mode. Each of these individuals has given me support in all that I have done. Throughout my life, they have demonstrated the values of hard work, kindness, honesty, and above all, unwavering faith in the Lord.

BIOGRAPHY

Todd Alan Spivey was the second son born to Rex Spivey and Debbie Barbour Spivey in Raleigh, North Carolina on 17 July 1990. He was raised in McGee's Crossroads community near Benson, NC where he graduated from West Johnston High School in 2008.

Todd was active in West Johnston High School's FFA chapter as well as the varsity baseball program.

In 2012, Todd graduated from North Carolina State University with a Bachelor's Degree in Turfgrass Science. During his time at North Carolina State University he was a member of the Agronomy Club and Turfgrass Club. In the summer of 2012, he was admitted into the graduate school of North Carolina State University in the Department of Crop Science. There, he began to pursue a Master's of Science under the direction of Dr. Keith Edmisten while working closely with Dr. Jack Bacheler and Dr. Dominic Reisig of the Entomology Department. While working towards his Master's Degree, Todd was given the opportunity to speak at field days and professional meetings. He served as president of the North Carolina State University Crop Science Graduate Student Association. Upon completion of his studies, Todd plans to continue his education by pursuing a Doctor of Philosophy in Crop Science with a focus in cotton production.

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LITERATURE REVIEW

Although approximately 5,000 species of thrips (Thysanoptera) have been identified, only a few hundred, mainly in the Thripidae family, are important pests of commercial crops (Lewis, 1997b). Though some tropical species of thrips adults may be up to 15 millimeters in length, the most common crop pests are no larger than one to two millimeters. These dorsoventrally flattened pests range from white, to yellow, to dark brown and black and can include dark bands around the abdomen (Moritz, 1997). On plants they look like pieces of dirt and light colored thrips can often visually blend with the plant to protect themselves from predators.

Mobility

Thrips are not strong flyers, but fringed wings coupled with relatively small size and light weight allows thrips to be moved long distances by wind. Even wingless thrips can be blown long distances as shown by Mound (1983) when wingless and winged thrips species were demonstrated to move over 1500 km across the Tasman Sea from Australia to New Zealand. Winged thrips have appendages that are covered in long, straight or wavy setae which are folded down at rest with the forewings covering the hind wings (Lewis, 1997a; Moritz, 1997; Mound, 1983). When at rest the wings are almost the length of the abdomen (Lewis, 1997a). When flying the setae are unfolded and arranged to increase wing surface area. Straight setae are located on the forward edge of the wings while longer, wavy setae are located on the rearward edge. This arrangement increases the surface area of the wings three to four times during flight (Lewis, 1997a). Alulae are scale-like structures located at the base of the wings that keep the fore- and hind wings beating synchronously (Lewis, 1997a; Moritz, 1997).

Feeding

Thrips species have different feeding guilds including those that are commonly found on cotton. Leaf feeding thrips include *Caliothrips spp.* and *Thrips palmi* (melon thrips) while *Thrips tabaci* (onion thrips) and *Frankliniella spp*. are considered bud feeders. Adults of the leaf feeding species are found on leaves while adults of bud feeding species are found in floral and vegetative buds. Immatures of both the leaf and bud feeding species can be found in buds and on leaf surfaces (Leigh, 1995).

The main feeding structure that contains and protects all other structures is the mouth cone, which is made up of the labrum and labium for the front and back respectively (Hemming, 1978; Kirk, 1997b). A single, needle-like mandible with no opening is used to puncture hard surfaces such as leaf cuticles and pollen grains (Childers & Achor, 1995; Hemming, 1978; Kirk, 1997b). Two independent maxillary stylets, that form a sucking tube when together, replace the mandible opening to empty the contents of leaf cells (Childers & Achor, 1995; Hemming, 1978; Kirk, 1997b). The mandible itself is immobile and controlled by contracting the mouth cone, unlike the maxillary stylets than can be protracted and retracted independently (Kirk, 1997b).

Though early literature stated thrips fed by rasping and sucking it has since been shown that thrips are piercing-sucking feeders (Childers & Achor, 1995; Chisholm & Lewis, 1984; Huckuba & Coble, 1991; Hunter & Ullman, 1992; Kirk, 1995). Huckaba and Coble

(1991) discovered when soybean thrips, *Neohydatothrips variabilis,* fed on soybean trifoliates there were no gashes or wounds, but rather punctures. Mesophyll cells beneath the punctured epidermis were emptied completely, causing epidermal tissue to collapse (Huckuba & Coble, 1991).

Reproduction

Most thrips species require mating of male and female adults. Female adults can however lay both fertilized and unfertilized eggs resulting in female and male offspring respectively, although there is little knowledge of how the fertilization is controlled (Moritz, 1997). According to Moritz (1997), temperature or the presence of microbes can affect sex of the offspring in some asexual species.

Eggs are often inserted into cotton leaves and completion of this stage ranges from three to fourteen days (Leigh, 1995). Two or more larval stages occur, the initial stages on the undersides of leaves or in buds and the final stage in the soil or other secluded places, before adults emerge in nine to twenty-three days from egg lay, dependent upon temperature (Leigh, 1995; Lewis, 1997b). *Frankliniella occidentalis,* western flower thrips, has been reported to survive up to 40 days and produce over 200 eggs on cotton (Trichilo & Leigh, 1988).

Weather

Heavy rains can be detrimental to thrips populations by washing thrips off plants, trapping them in the soil, or drowning thrips in small puddles (Kirk, 1997a; Morsello et al., 2008; North & Shelton, 1986b). Though many dead thrips can be found stuck to wet leaves, trapped in the wet soil, or drowned in crevices found in plants, some thrips can survive heavy rains by remaining on the underside of leaves (Bailey, 1934; Kirk, 1997a; North & Shelton, 1986a). Although heavy rainfall can be detrimental to thrips mechanically, submersion in water in general is not as detrimental to thrips survival. Thrips larvae have been known to survive 48 to 72 hours under water, while adults can survive almost 24 hours (Bailey, 1934; Brodsgaard, 1993). Rain also means plant growth and often delayed senescence of thrips' winter hosts. Increased plant growth and presence of winter hosts allow for increased population growth (Morsello et al., 2008) but often a reduction in plant damage. As leaf area increases, thrips densities decrease per unit surface area, resulting in less injured leaf area and healthier plants.

Not only can heavy rains harm thrips, but dry weather can affect thrips as well. Thrips are very sensitive to dry microclimates and low relative humidity (Laughlin, 1977; Lewis, 1962). According to Laughlin (1977), gum tree thrips, *Thrips australis*, adults can survive almost three days at 50% humidity when water is available but only 10 hours when water is not available. Larvae are generally more susceptible to low humidity, and most thrips thrive at 70 to 90% humidity (Kirk, 1997a; Laughlin, 1977; Shipp & Gillespie, 1993).

Cold weather can also have a detrimental effect on thrips of most species. Western flower thrips adults can survive up to 35 days at 0° C, more than two days at -5° C and only one day at -10° C (Brodsgaard, 1993; Felland et al., 1993). Grain thrips, *Limothrips cerealium*, adults can survive lower temperatures for a longer duration than Western flower thrips but still only two days at -10° C (Lewis, 1962).

Thrips can survive warm temperatures easier than cold, given that relative humidity is high. Onion thrips breed and develop readily up to 30° C, though their feeding may decline at greater temperatures (Kirk, 1997b; MacGill, 1937). The greater the temperature, the higher the relative humidity needs to be for thrips survival, which could be due to greater activity and water loss (Kirk, 1997a). Shipp and Gillespie (1993) used temperature as a sanitation method for greenhouses, stating that all stages of western flower thrips could be eliminated if the controlled temperature reached at least 40° C with a relative humidity of at least 36%. Temperature, warm or cold, influences thrips populations primarily due to the effect it has on thrips development (Morsello et al., 2008).

Thrips as Pests

Thrips have long been noted as major agricultural and horticultural pests. According to Quayle (1938), losses of up to 80 per cent were seen in California's citrus crops caused by citrus thrips, *Scirtothrips citri*. In 1993, western flower thrips and melon thrips caused over 10 million dollars in damage to sweet peppers in Florida (Nuessly & Nagata, 1995). Though newer methods of control are now available to reduce pest issues, thrips can still cause major losses in some parts of the world.

North Carolina Cooperative Extension's Cotton Information booklet states that thrips can be North Carolina's most economically damaging insect pest complex (Reisig & Bacheler, 2014). Thrips have the potential to cause significant yield loss and maturity delay in cotton. Therefore, growers must control this pest every season.

Three major species compose the main focus of thrips damage in North Carolina cotton, all in the Thripidae family. *Frankliniella fusca,* tobacco thrips, are generally dark brown in color, tend to be the most common thrips on cotton, and are native to North Carolina (Cho et al., 1995). Cho et al. (1995) collected thrips samples from overwintering sites across North Carolina from 1990 to 1992, 92% of which were tobacco thrips. A study conducted in Northwest Florida observed higher densities of adult tobacco thrips on cotton seedlings compared to other *Frankliniella* species (Osekre et al., 2009). Brachypterous, reduced wing, females are the dominant form of overwintering tobacco thrips, transitioning to macropterous, winged, females in the spring (Groves et al., 2001).

Frankliniella occidentalis, western flower thrips, are large thrips, about one to two millimeters, and are generally yellow in color. Western flower thrips are not as common as tobacco thrips but are important because they can be difficult to control and have the ability to build up resistance to chemical control methods (Eger et al., 1998; Espinosa et al., 2002; Jenson, 2000). In the above study by Cho et al. (1995) while 253 tobacco thrips adults were found, only seven western flower thrips adults were found.

Thrips tabaci, onion thrips, is another major thrips pest species found in early season cotton. Onion thrips are about one to one and a half millimeters in length and are generally yellow in color often with dark brown bands on their abdomen (Alston & Drost, 2008). Onion thrips can overwinter in North Carolina and have been found on wild hosts as well as winter crops (Cho et al., 1995; North & Shelton, 1986c). Cho et al. (1995) found only eight onion thrips on wild hosts overwintering across the state compared to 253 tobacco thrips and seven western flower thrips. Though less common than tobacco thrips, onion thrips can still be a major pest in North Carolina cotton.

Thrips Damage to Cotton

Thrips are an early season cotton pest, generally from two to five weeks after planting (WAP), and can be a damaging pest even with modern control methods including insecticidal seed treatments and foliar insecticide applications. A study of thrips monitoring methods on cotton in Louisiana showed adult and immature thrips population densities peaked at 20 to 28 days after planting (Burris et al., 1990). Thrips attack terminal buds, young cotyledons and true leaves on seedling cotton. Thrips damage often takes the form of curled, ragged, and crinkled leaves as they begin to expand (Childers, 1997; Reisig & Bacheler, 2014; Terry & Barstow, 1988). The majority of early leaf injury is caused by thrips feeding in the bud area which subsequently results in symptoms on unfurling leaves (Leigh, 1995). This damage causes stunting in plants along with the loss of lower fruiting positions, resulting in delayed maturity. Severe damage can additionally cause terminal bud death, multiple branching due to loss of apical dominance, and two to three week delay of fruit set (Childers, 1997; Leigh, 1995; Reisig & Bacheler, 2014). Thrips-damaged seedlings can also be more susceptible to seedling diseases (Quisenberry & Rummel, 1979). It is rare that thrips cause damage to seedlings beyond the five to six weeks after planting; therefore the five to six weeks after planting is considered the critical period that growers need to reach to be clear of additional thrips damage (Leigh, 1995).

Thrips damage can become more severe in years that are not conducive to rapid seedling growth. Slow growing seedlings due to cool, wet weather can keep plants in a susceptible stage longer than normal (Rummel et al., 1988). Dry weather can reduce uptake of at-planting insecticides as well as force thrips off their over wintering hosts early (Reisig & Bacheler, 2014).

Literature going back to the late 1930's shows that thrips can damage and stunt growth of cotton seedlings though a reduction of yield is not always observed. One South Carolina study showed thrips injury delayed and shortened blooming period by 10 days and was correlated with a 40% reduction in bolls resulting in a 40% loss of seed cotton yield (Watts, 1937). A study conducted in Texas by Quisenberry and Rummel (1979) showed that only at-planting systemic insecticides used to control thrips increased yields compared to a foliar application after infestation has occurred, which did not increase yields compared to an untreated check. Two studies, in Israel and Georgia, also show that multiple branching, due to loss of apical dominance from thrips damage, can reduce lint yield as much as 40% and delay first bloom by as much as two weeks (Ballard, 1951; Klein et al., 1986).

Harp and Turner (1976) used leaf area to quantify thrips damage and showed that reduced leaf area, by thrips injury, up to 70% did not result in reduced yield in the Texas blacklands. Another study in southeastern Australia, near Sydney, conducted from 1995 to 2001 showed cotton seedlings manually defoliated completely, to simulate thrips injury, before the first flower bud appeared, did not differ in yield from healthy plants (Wilson et al., 2003). Lei and Wilson (2004) theorized this was due to increased leaf area compensation. When thrips-injured leaves with dead cells continued to grow, less energy is needed because fewer cells were expanding. Therefore cell expansion in damaged leaves is completed sooner, allowing the plant to divert energy to new upper leaves sooner than that of non-damaged plants, helping the damaged plants compensate for lost cells (Lei & Wilson, 2004).

Though there is research showing cotton has the ability to compensate for early season damage and stress, this can only occur in growing seasons that are conducive for cotton growth. Years in which excess rain, and the cool, cloudy weather associated with rain, dominates the spring, early season damage is exacerbated by environmental stresses. These conditions can delay maturity and reduce the plants ability to compensate for the early season damage and stresses. In the presence of such stresses, complete prevention of thrips injury is the key to increasing cotton lint yield (Quisenberry & Rummel, 1979).

Thrips Management in Cotton

Aldicarb (sold as Temik 15G), an at-planting, systemic carbamate was used for the control of thrips for over 40 years. First registered in 1970 with the EPA, aldicarb had a long history of negative impacts on the environment (Bradbury, 2007). In 2010, however, Bayer Crop Science and the EPA came together on a decision to remove aldicarb from the market and phase out all uses of the product, thus, significantly reducing options for early season thrips management (EPA, 2010).

Insecticidal seed treatments are now used on most cotton acres in the Southeast United States to manage thrips. There are several commercial options for growers including various brands containing the insecticides thiamethoxam, imidacloprid, and clothianidin. These insecticidal seed treatments generally give 10 to 21 days of protection to seedlings and a foliar insecticide application is recommended to help give extended control (Reisig & Bacheler, 2014). Almost 90% of North Carolina's cotton acres have been treated with a foliar application since 2009 (Bacheler, unpub. data).

Cultural Management of Thrips

Thrips abundance can also be reduced by cultural practices. To help manage thrips, it is important to understand populations in adjacent fields (Parrella & Lewis, 1997). Tobacco thrips and onion thrips are both cotton pests of North Carolina with the ability to overwinter even through cold temperatures (Cho et al., 1995; North & Shelton, 1986c). Though North and Shelton (1986c) reported onion thrips overwintering on winter wheat and alfalfa in New York, Cho et al. (1995) only found tobacco thrips overwintering on any of the five economic crops sampled in North Carolina. According to Cho et al. (1995), tobacco thrips is the most common overwintering thrips in North Carolina, found on at least 30 different wild hosts as well as five winter crops.

Planting date has a significant effect on thrips abundance in cotton (Parajulee et al., 2006; Parrella & Lewis, 1997). Late-planted cotton has been found to have fewer thrips than a timely planted crop, possibly due to the amount of other hosts available (Parajulee et al., 2006). Though late planting dates may offer a reduction in thrips abundance, cotton planting is often dictated by temperatures and rainfall. Planting later to avoid thrips may not be feasible for growers, especially those planting large acreage and those constrained by length of growing season (Leigh, 1995).

Conservation tillage was also found to reduce western flower thrips numbers three fold when compared to conventional tillage in the Texas High Plains (Parajulee et al., 2006). Another study showed that using any winter cover crop followed by strip tillage significantly reduced thrips abundance (Toews at al., 2010). Toews et al. (2010) attributed the reduction of thrips abundance to increased ground cover, showing inverse correlations between ground cover and thrips abundance at four of six sampling dates. This same study showed thrips pressure reached economic thresholds less than half as often when using strip tillage than when using conventional tillage (Toews et al., 2010). Pubescent varieties can also offer some resistance to leaf feeding thrips species, with increasing degrees of pubescence offering greater resistance, but not to bud feeding species such as *T. tabaci* and *Frankliniella spp.* (Leigh, 1995; Quisenberry & Rummel, 1979).

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IMIDACLOPRID APPLICATION METHOD OFFERS POTENTIAL ONE TIME TREATMENT OPTION FOR CONTROL OF HIGH THRIPS POPULATIONS IN UPPER SOUTHEAST

IMIDACLOPRID APPLICATION METHOD OFFERS POTENTIAL ONE TIME TREATMENT OPTION FOR CONTROL OF HIGH THRIPS POPULATIONS IN UPPER SOUTHEAST

Todd A. Spivey

Jack S. Bacheler

Keith L. Edmisten

North Carolina State University

Raleigh, NC

Dominic D. Reisig

North Carolina State University

Plymouth, NC

ABSTRACT

North Carolina Extension recommendations for thrips control in cotton consist of an insecticide seed treatment and follow up foliar application, if warranted. This foliar application is generally an acephate foliar spray, often tank mixed with an herbicide for an early post application for weed control. Often timed for weed control, the acephate application may miss the critical window for thrips management (first true leaf stage). Acephate has also been shown to increase the potential for twospotted spider mite (*Tetranychus urticae*) and cotton aphid (*Aphis gossypii*) issues later in the growing season due to disruption of beneficial insects and hormoligosis. Despite the potential dangers, at least 88% of North Carolina's cotton acres have been treated with a foliar application for thrips control since 2009. The objective of our research was to investigate a possible single treatment option (at-planting treatment only) for management of high thrips population densities, thus eliminating the need for a subsequent foliar application. Treatments consisted of an untreated check with a base fungicide seed treatment, seed treated with thiamethoxam, and seed treated with thiamethoxam combined with imidacloprid applied in-furrow at 657 ml ha^{-1} with a single stream of finished product, with 84 l ha^{-1} at 83 kPa, through a #55 orifice disc. The treatments were applied in a strip plot design in 2012 with four replications and in 2013 with five replications. Thrips were sampled at two, three, and four weeks after planting (WAP). Imidacloprid in-furrow with thiamethoxam seed treatment reduced thrips densities compared to the untreated check at all sampling dates and reduced densities compared to the thiamethoxam seed treatment alone at four WAP in 2012 and at three and four WAP in 2013. There were no yield differences in 2012, whereas imidacloprid applied in-furrow with a

thiamethoxam seed treatment increased yield compared to all other treatments in 2013. Well timed rain and good growing conditions during boll set in 2012 likely allowed untreated check and thiamethoxam seed treatment plots to compensate for early season thrips damage. Thrips levels were extremely high in both 2012 and 2013. Due to the reduced thrips densities, differences in most of the other plant growth parameters measured, and yield data, imidacloprid in-furrow with thiamethoxam seed treatment offers the potential for a single treatment option for high thrips population densities, eliminating the need for a subsequent foliar application.

INTRODUCTION

North Carolina growers have applied a foliar application to control early season thrips (Thysanoptera: Thripidae) on approximately 90% of their acres since 2009 (Bacheler, unpub. data). Insecticidal seed treatments, such as imidacloprid and thiamethoxam, generally manage thrips until approximately 10 to 21 days after planting. Cooperative Extension recommendations include a foliar application to extend management, providing cotton seedlings additional protection for up to five weeks after planting (WAP) (Reisig & Bacheler, 2014). This application is generally made using the insecticide acephate (Orthene 97, AMVAC Chemical Corporation, Los Angeles, CA) and is applied around the one true leaf stage for maximum effectiveness. This application can also be applied in a tank mix with an early postemergence herbicide for convenience to the grower (Miller et al., 2005).

A foliar application, specifically acephate, may not be the best option for thrips control and it has its downfalls. Delayed application due to weather or timing with herbicide application can allow thrips populations to increase well beyond economic threshold levels. Allowing populations to exceed economic threshold levels can both delay maturity and reduce yields; therefore timely applications are important (Quisenberry & Rummel, 1979). Moreover, acephate, a broad spectrum organophosphate, can also be disruptive to beneficial insects. Acephate has been shown to reduce *Orius insidiosus* (insidious flower bug) levels; this insect is a known predator of thrips (Reitz et al., 2003). Acephate also flares spider mites and has even been used to flare spider mites in field experiments (Reisig & Godfrey, 2006). A reduction in the number of acres sprayed with acephate would also be favorable because acephate is not very effective against *Frankliniella occidentalis,* western flower thrips. One study conducted on field grown peppers showed the high population abundances of western flower thrips, commonly found on cotton in North Carolina, can remain after acephate treatments and that population abundances can even increase after applications (Reitz et al., 2003). Similar observations have been made both by extension cotton entomologists and independent crop consultants in the upper Southeast.

In addition, some varieties may receive injury from tank mixes of acephate and glufosinate. The *pat* gene was used, in WideStrike (Phytogen, Dow AgroScience, Indianapolis, IN) cotton varieties, as a marker to determine the presence of a closely-linked insecticidal gene and the protein produced by the marker gene was found to confer tolerance to herbicidal activity by glufosinate (Barnett et al., 2012). However, when the gene is used as a marker in WideStrike cultivars, the enzyme conferring tolerance occurs at lower levels than other varieties that use a separate event to confer complete glufosinate tolerance increasing the potential for phytotoxicity from glufosinate in WideStrike varieties (Culpepper et al., 2009; OECD, 2002; Whitaker et al., 2011). A reduction in acephate applications would reduce the stress and injury on cotton varieties already at a risk for injury from the herbicide alone.

Imidacloprid is a neonicotinoid-class insecticide first registered with the EPA in 1994 by Bayer Crop Science (NPIC, 2010). The systemic insecticide, imidacloprid, is used to control piercing-sucking insects as well as some chewing insects. Imidacloprid can be used as a seed treatment, at planting in-furrow, as a soil drench, and as a foliar spray (NPIC, 2010). Imidacloprid as a seed treatment has been shown to give control of thrips up to six

WAP on cotton (El-Naggar & Zidan, 2013), although control of thrips on cotton in the upper Southeast is typically in the range of 10 days to three WAP.

This study was conducted to evaluate the use of imidacloprid applied in-furrow with a neonicotinoid seed treatment to manage high thrips population abundances on cotton in the upper Southeast.

MATERIALS AND METHODS

Phytogen 499 WRF (Dow AgroScience, Indianapolis, IN) was planted 1 May 2012 and 13 May 2013 in Wilson, NC and, with the exception of at-planting thrips control treatments, cotton was managed using the North Carolina Cooperative Extension Service recommended practices.

Treatments were arranged in a strip plot design with four replications in 2012 and five replications 2013. In 2012, each plot was 3.7 m wide (four rows with 0.9 m row width) and ranged from 149.9 to 154.9 m in length; it was planted to 12.3 plants per m (134,492 plants ha^{-1}) on a Marlboro sandy loam. In 2013, each plot was 3.7 m wide (four rows with 0.9 m row width) by 15.2 m long; it was planted to 12.3 plants per m (134,492 plants ha^{-1}) on a Varina sandy loam.

Treatments consisted of a base fungicide seed treatment check containing the fungicides fludioxynil (Maxim, Syngenta Crop Protection, Greensboro, NC) at 0.20 ml kg^{-1} seed, mefenoxam (Apron XL, Syngenta Crop Protection, Greensboro, NC) at 0.052 ml kg^{-1} seed, myclobutanil (Nuflow M, Wilbur-Ellis Agribusiness, Fresno, CA) at 1.138 ml kg^{-1} seed, and benzothiazole (Nusan 30, Wilbur-Ellis Agribusiness, Fresno, CA) at 0.813 ml kg^{-1}

seed as well as the organophosphate insecticide, chlorpyrifos (Lorsban, Dow AgroSciences, Indianapolis, IN) at 0.065 ml kg^{-1} seed; Avicta Complete seed treatment (Syngenta Crop Protection, Greensboro, NC) containing the insecticide thiamethoxam (Cruiser, Syngenta Crop Protection, Greensboro, NC) at 0.375 mg/seed, the fungicide azoxystrobin (Dynasty CST, Syngenta Crop Protection, Greensboro, NC) at 0.03 mg/seed, and the nematicide abamectin (Avicta, Syngenta Crop Protection, Greensboro, NC) at 0.15 mg/seed; and thiamethoxam seed treatment with imidacloprid (Admire Pro 4.6F, Bayer Crop Science, Research Triangle Park, NC) applied in-furrow at 657 ml ha^{-1}. Imidacloprid was applied in-furrow using drop nozzles from a tractor mounted tank. A single #55 orifice was used to deliver a single stream of finished product approximately six inches above the open furrow at 84 l ha^{-1}, 83 kPa, and five km h^{-1} per row.

To quantify thrips abundance, samples were taken at two, three, and four WAP by cutting five plants per plot at the soil surface using a straight razor to minimize disturbance to plants and thrips. The cut plants were immediately placed into a pint or quart glass jar containing a soapy water solution for transport to the lab. Plants were washed onto a 270-mesh screen with 0.053 mm openings and any material retained was rinsed into six dram vials of 70% alcohol solution for storage (Reisig & Godfrey, 2006). The material and solution was rinsed into a Petri-dish and adult and immature thrips were counted using a 0.7 to 3.0 x Bausch and Lombe stereo dissecting microscope with 10x occulars. Thrips adults from the untreated check plots were removed and were later identified to species. The sampled plants were allowed to dry down for seven days at room temperature; dry weights were recorded per five plant sample.

At each sampling date, the number of true leaves, plant height, a visual thrips injury rating, and a visual vigor rating were also recorded for 10 randomly selected plants per plot. Leaves were counted as a true leaf when reaching the approximate area of a dime. Plant height was measured from the soil line to the terminal bud. Thrips injury ratings were based on a scale from one to five where a one is no injury and a five is near plant death (Faircloth et al., 2001). Vigor ratings provided visual ratings of the health of seedlings in consideration of thrips damage. Vigor ratings were based on overall plant health taking into account the amount of thrips injury, plant height, approximate leaf area and overall plant size. Vigor ratings were based on a scale from one to five where a one is the healthiest plants with little thrips injury, the greatest plant heights, and large leaf areas while a five is the least vigorous plants with increased thrips injury, shorter plant heights, and little leaf area. Stand counts were taken from a randomly selected three meter section of the two center rows of each plot.

The two center rows were harvested with a two row John Deere 9930 cotton picker equipped with a Rice Lake Weighing System Model 920i weight indicator with Cotton Data Software package (Master Scales, Greenwood, MS) to determine seed cotton weight per plot. This value was converted to lint yield per acre based on 0.40 seed cotton to lint conversion. Cotton was harvested on 20 October 2012 and 31 October 2013.

Data were incorporated in an analysis of variance model using the PROC GLM procedure in SAS 9.3 (SAS Institute Inc., Cary, North Carolina). Included in the model were independent variables block, treatment, and year. An interaction between treatment and year was observed; therefore, data from each year were analyzed and are presented separately. Treatment means were separated using Fisher's Protected LSD test at $P \leq 0.05$.

RESULTS & DISCUSSION

Species Composition

Frankliniella fusca, tobacco thrips, was the most common pest species found in the untreated checks in both 2012 and 2013 (Table 1) which is consistent with what Cho et al. (1995) found in a study of overwintering thrips in North Carolina in which 94% of the thrips found were tobacco thrips. Overwintering species distributions often correlate with early season species distribution in cotton due to the timing of seedling emergence and die back of overwintering hosts. In our studies, tobacco thrips accounted for 85% or more of the population at four of six sampling dates over the two years and all three samples taken in 2013. This observation is also consistent with findings from North Florida in which tobacco thrips were the most common *Frankliniella* species found on seedling cotton (Osekre et al., 2009). With the exception of three WAP in 2012, *Thrips tabaci*, onion thrips, accounted for the remainder of the population. Onion thrips accounted for 35% of the population at two WAP in 2012. At three WAP in 2012, the population was much more diverse than any other sampling date. Tobacco thrips and onion thrips accounted for approximately 30% of the species distribution each and *Frankliniella tritici*, eastern flower thrips, also accounted for about 25% of the population. *Neohydatothrips variabilis*, soybean thrips, at 14% and western flower thrips, at one percent were also present at three WAP in 2012.

Thrips Abundance

In 2012 and 2013, the seed treatment plus the imidacloprid in-furrow spray with thiamethoxam seed treatment reduced thrips populations at two, three, and four WAP when compared to populations in untreated check plots (Table 2). Imidacloprid with a thiamethoxam seed treatment reduced immature thrips abundance by more than 95% at both two and three WAP in both 2012 and 2013. At four WAP, immature counts were reduced by nearly 70% when compared to the both the untreated check and the seed treatment alone.

Thiamethoxam reduced immature thrips numbers when compared to the check at two and three WAP in both 2012 and 2013. In 2012, at two WAP, thiamethoxam reduced immature thrips abundance by as much as 90%. At three WAP, thiamethoxam again reduced immature thrips abundance when compared to the untreated check by 80%. As in 2012, thiamethoxam seed treatment reduced thrips counts compared to the untreated check at two and three WAP by approximately 90% and 50% respectively in 2013. At four WAP however, the thiamethoxam seed treatment alone did not reduce thrips abundance compared to the untreated check in both 2012 and 2013.

Adult thrips were reduced by imidacloprid in-furrow with a thiamethoxam seed treatment at two WAP in 2013 (Table 3). In 2012, thiamethoxam seed treatment plots had more adult thrips at four WAP compared to the untreated checks (Table 3) perhaps partially due to increased plant matter with the seed treatment compared to the untreated check plots (Table 4). Total thrips abundance followed the same trends as immature thrips counts in 2012 and 2013 (data not shown).

Dry Weight

Treatment differences were only observed at four WAP in 2012. Plots treated with imidacloprid in-furrow and a thiamethoxam seed treatment increased dry weight per plant compared to the untreated check and seed treatment alone. Thiamethoxam seed treatment alone increased dry weight per plant when compared to the untreated check. The plots treated with imidacloprid in-furrow and a thiamethoxam seed treatment had on average more than double the dry weight than the untreated check plots at four WAP in 2012 as well as three and four WAP in 2013.

In 2013, the seed treatment alone and the seed treatment plus imidacloprid applied in-furrow increased dry weight per plant when compared to the untreated check at all three sampling dates. Imidacloprid in-furrow with seed treatment increased dry weight at all sampling dates and compared to thiamethoxam seed treatment at two and four WAP. Thiamethoxam seed treatment increased the dry weight per plant at two and four WAP but not at three WAP in 2013 compared to the untreated check. This increase in biomass compared to the untreated check can help explain why thiamethoxam seed treatment did not reduce thrips abundance compared to the untreated check at four WAP. The plants in the untreated check plots had less plant matter for thrips to feed and therefore had lower counts at four WAP.

Thrips Injury Rating

Thrips injury ratings were lower in both treatments compared to the untreated check at two, three, and four WAP in both 2012 and 2013 (Table 5). Imidacloprid in-furrow with seed treatment received lower injury ratings at all sampling dates when compared to both the seed treatment alone plots as well as the untreated check plots. Thiamethoxam seed treatment also reduced injury ratings compared to the untreated check plots at all sampling dates. In 2013, thrips injury was so severe in the untreated check plots that it caused some plant death as indicated by lower stand counts.

Vigor Rating

Vigor ratings were only taken at three and four WAP in 2012 and were positively affected by both treatments compared to the untreated check at both sampling periods (Table 5). Plots receiving imidacloprid in-furrow with seed treatment earned the best vigor ratings followed by thiamethoxam seed treatment plots and then the untreated check plots. Vigor ratings were not taken in 2013.

Plant Height

In 2012, both treatments showed greater plant heights at two and three WAP and at all sampling dates in 2013 compared to the untreated check (Table 5). At two WAP in 2012, imidacloprid in-furrow with seed treatment and thiamethoxam seed treatment alone increased plant height when compared to the untreated check. Imidacloprid in-furrow increased plant height compared to thiamethoxam seed treatment which increased plant height compared to the untreated check at three WAP. No effects were observed at four WAP.

In 2013, imidacloprid in-furrow with a thiamethoxam seed treatment plots had taller plants at two and four WAP compared to thiamethoxam seed treatment and the previous two treatments also had taller plants during all sampling dates compared to the untreated check. At four WAP imidacloprid in-furrow with seed treatment plots were an average six cm taller than thiamethoxam seed treatment, and 12 cm taller than the untreated check plots.

Number of True Leaves

Treatment differences were observed in the number of true leaves at all sampling dates compared to the untreated check in 2012 and 2013 (Table 5). Imidacloprid in-furrow with seed treatment had more true leaves per plant than the plots with seed treatment alone and the untreated checks at two and three WAP. Imidacloprid in-furrow with seed treatment and the seed treatment alone had more true leaves per plant than did the untreated check plots at four WAP.

In 2013 at two WAP, imidacloprid in-furrow with seed treatment had more true leaves than thiamethoxam seed treatment alone. At all sampling dates in 2013, untreated check plots had at least one true leaf fewer than that of the imidacloprid in-furrow plots. This data shows the maturity difference in plots even at an early stage.

Stand Count

Stand counts were taken after early season thrips pressure so seedling death due to thrips damage were quantified. Stand counts were not affected in 2012, but, in 2013, imidacloprid in-furrow with seed treatment and thiamethoxam seed treatment had greater final stands than the untreated check plots (Table 6). Untreated check plots averaged at least five fewer plants when compared to imidacloprid and seed treatment only plots. That loss of plants due to thrips damage equates to losing almost 0.5 m of plants for every 3 m of row or about 17,000 plants ha^{-1}.

Yield

Thrips control treatments did not increase yield in 2012, although only two replications were included in this comparison due to a weigh system malfunction (Table 7). Additionally, the 2012 growing season offered unusually good late-season growing conditions, allowing the untreated check and seed treatment alone plots to compensate for early thrips damage. Wilson, NC received 25 and 21.6 cm of rain in July and August 2012, respectively, which provided ample water during reproductive growth of cotton (Table 8). Coupled with adequate heat units (Young et al., 1980), cotton that was injured by thrips was able to compensate and grow out of damage. All three treatments averaged between 1277 to 1344 kg lint ha^{-1}. These results are consistent with findings by several authors; cotton has been shown to have the ability to grow out of injury from 70 to 100% leaf damage under good compensatory growth conditions (Harp & Turner, 1976; Wilson et al., 2003).

Unlike 2012, yields differed according to thrips treatment in 2013 (Table 7). The 2013 growing season did not offer good conditions for late-season compensation (Reddy et al., 1991); therefore, early season thrips management caused an increase in yield compared to the lack of differences in 2012. Imidacloprid in-furrow with seed treatment had increased yields compared to both thiamethoxam seed treatment and the untreated check plots. Imidacloprid in-furrow with seed treatment yielded 1465 kg of lint ha^{-1}, 25% higher than thiamethoxam seed treatment and 46% higher than the untreated checks. In 2013, Wilson had an uncharacteristically cool spring with excessive rainfall. Wilson received 33 cm of rain in June alone (Table 8) compared to the 10 cm average for the month of June from 2002 through 2012 (CRONOS, 2013). May 2013 received over 100 heat units fewer than May

2012 and at least 60 heat units fewer than that in 2010 and 2011. The excess rain, cloudy weather associated with the rain, and lack of heat likely delayed plant maturity considerably compared to recent years, and did not allow the untreated check and thiamethoxam seed treatment plots to compensate for early season thrips damage.

SUMMARY

Judging from a combination of all parameters evaluated in 2012 and 2013, cotton seedlings in the treated seed plus imidacloprid in-furrow spray plots did not met the NCSU-recommended threshold for a follow-up foliar spray. This was also observed at the same location in a similar test in 2011 (not included in this paper). Although the seed treatment plus in-furrow spray approach should be evaluated at additional locations before being widely adopted by producers, our data suggests that this approach could offer cotton producers in the upper Southeast an at-planting option that would avoid the widespread use of a follow-up, sometimes disruptive, foliar spray.

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Table 1. Adult thrips species composition in check plots (20 plants) at each sampling date in 2012 and 2013 in Wilson, NC.

	Thrips Species -------------------- Thrips per 20 plants --------------------				
Date	***F. fusca*[z]**	***F. occidentalis*[y]**	***T. tabaci*[x]**	***F. tritici*[w]**	***N. variabilis*[v]**
2012					
17 May	68	0	9	0	0
24 May	28	0	16	1	0
31 May	6	1	6	5	3
2013					
30 May	88	0	2	0	0
6 June	54	0	8	0	0
13 June	50	0	0	0	2

[z] *Frankliniella fusca*, Tobacco thrips

[y] *Frankliniella occidentalis*, Western flower thrips

[x] *Thrips tabaci*, Onion thrips

[w] *Frankliniella tritici*, Eastern flower thrips

[v] *Neohydatothrips variabilis*, Soybean thrips

Table 2. Number of immature thrips at two, three, and four weeks after planting per five plants for 2012 and 2013.

	2 WAP[y]		3 WAP		4 WAP	
Treatment	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Untreated Check	68 a[z]	193 a	250 a	166 a	102 a	139 a
Thiamethoxam seed treatment	5 b	22 b	47 b	81 b	125 a	175 a
Imidacloprid in-furrow plus seed treatment	2 b	3 c	9 b	4 c	32 b	43 b
LSD[x]	21	14	63	17	35	37

[z] Means in the same column followed by the same letter are not significantly different.

[y]WAP – Weeks after planting

[x]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 3. Number of adult thrips at two, three, and four weeks after planting per five plants for 2012 and 2013.

	2 WAP[y]		3 WAP		4 WAP	
Treatment	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Untreated Check	22	23 a[z]	12	15	10 a	13
Thiamethoxam seed treatment	21	16 b	16	18	7 a	12
Imidacloprid in-furrow plus seed treatment	13	8 c	9	14	5 b	9
LSD[x]	NS	5	NS	NS	3	NS

[z] Means in the same column followed by the same letter are not significantly different.

[y]WAP – Weeks after planting

[x]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 4. Thrips management treatment differences of dry weight at Wilson, NC in 2012 and 2013.

Treatment	2012			2013		
	2 WAP[y]	3 WAP	4 WAP	2 WAP	3 WAP	4 WAP
	-------------------- grams per plant -------------------------					
Untreated Check	0.160	0.271	0.352 c[z]	0.155 c	0.273 b	0.326 c
Thiamethoxam seed treatment	0.169	0.346	0.634 b	0.197 b	0.402 ab	0.762 b
Imidacloprid in-furrow plus seed treatment	0.174	0.341	0.784 a	0.231 a	0.517 a	1.330 a
LSD[x]	NS	NS	0.101	0.028	0.135	0.254

[z] Means in the same column followed by the same letter are not significantly different.

[y]WAP – Weeks after planting

[x]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$.

Table 5. Thrips management treatment differences in thrips injury rating, vigor rating, plant height, and number of true leaves.

	2012				2013			
	UC[y]	AC[x]	AP[w]	LSD[v]	UC	AC	AP	LSD
Thrips Injury Rating[u]								
2 WAP[t]	4.1 a[z]	2.7 b	1.8 c	0.2	4.1 a	2.9 b	1.6 c	0.1
3 WAP	3.9 a	2.8 b	2.0 c	0.2	4.4 a	3.0 b	1.3 c	0.2
4 WAP	4.0 a	2.7 b	1.7 c	0.2	4.6 a	3.2 b	1.0 c	0.1
Vigor Rating[u]								
2 WAP	-	-	-	-	-	-	-	-
3 WAP	4.0 a	2.9 b	2.1 c	0.4	-	-	-	-
4 WAP	3.9 a	2.7 b	1.6 c	0.2	-	-	-	-
Plant Height	----------cm----------				----------cm----------			
2 WAP	5.6 c	6.8 b	7.1 a	0.3	5.3 a	6.2 b	7.8 a	0.3
3 WAP	8.4 c	10.2 c	11.1 c	0.4	9.1 c	11.1 b	12.5 a	0.7
4 WAP	16.8	18.0	18.1	NS	11.6 c	17.6 b	23.2 a	0.6
Number of True Leaves								
2 WAP	1.0 c	1.4 b	1.7 a	0.1	0.9 c	1.4 b	2.0 a	0.1
3 WAP	2.1 c	2.8 b	3.2 a	0.2	2.1 c	3.3 b	3.9 a	0.3
4 WAP	5.0 b	5.5 a	5.7 a	0.3	5.5 c	6.2 b	6.6 a	0.2

[z]Means in the same row and year followed by the same letter are not significantly different.

[y]UC – Untreated check

[x]AC – Thiamethoxam seed treatment

[w]AP – Imidacloprid in-furrow plus thiamethoxam seed treatment

Table 5 continued.

[v]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$.

[u]Thrips damage rating and vigor rating are based on a one to five scale with one being no damage and five being dead plants

[t]WAP – Weeks after planting

Table 6. Thrips management treatment differences in stand counts in 2012 and 2013 in Wilson, NC.

	plants per 3 m	
Treatment	**2012**	**2013**
Untreated Check	25	20 b[z]
Thiamethoxam seed treatments	26	25 a
Imidacloprid in-furrow plus seed treatment	27	28 a
LSD[y]	NS	4

[z] Means in the same column followed by the same letter are not significantly different.

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$.

Table 7. Impact of treatment differences on lint yield in 2012 and 2013 in Wilson, NC.

	Yield ------------------------ kg lint ha^{-1} ------------------------	
Treatment	**2012**	**2013**
Untreated Check	1277	679 c[z]
Thiamethoxam seed treatment	1344	939 b
Imidacloprid in-furrow plus seed treatment	1310	1182 a
LSD[y]	NS	228

[z] Means in the same column followed by the same letter are not significantly different.

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$.

Table 8. Precipitation (cm) per month in Wilson, NC from April to October in 2012 and 2013.[z]

Month	2012	2013
	----------cm----------	
April	7.82	7.62
May	15.19	9.75
June	5.03	33.20
July	25.10	15.52
August	21.62	4.90
September	6.50	10.01
October	7.09	9.47
Total	**88.34**	**90.47**

[z] CRONOS database - State climate office of North Carolina. 2013. Retrieved 12 December 2013 from http://www.nc-climate.ncsu.edu/cronos.

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Todd A. Spivey

Jack S. Bacheler

Keith L. Edmisten

North Carolina State University

Raleigh, NC

Dominic D. Reisig

North Carolina State University

Plymouth, NC

ABSTRACT

Thrips can be North Carolina's most economically damaging insect complex in cotton. Thrips have the potential to cause significant cotton yield loss and maturity delay; therefore annual control is recommended. Thrips in North Carolina are primarily controlled by seed treatments and routine foliar applications at the one to two leaf stage. Our research was conducted to compare seed treatments and in-furrow insecticide applications with and without a follow up foliar application. Trials were conducted in two North Carolina locations during 2012 and 2013. All treatments included a base fungicide treatment plus additional insecticidal treatments. The control consisted of the base fungicide alone. Insecticidal seed treatments were Avicta Complete seed treatment, Acceleron N seed treatment, Poncho/VOTIVO/Aeris seed treatment, and a non-commercial imidacloprid seed treatment at 3 mg per seed. An additional treatment was base fungicide seed treatment with an in-furrow application of Admire Pro at 621 ml ha^{-1}. The untreated check with base fungicide seed treatment, Avicta Complete seed treatment, Acceleron seed treatment, and the Poncho/VOTIVO/Aeris seed treatment each also received a foliar application of Orthene 97 at 0.36 kg ai ha^{-1}. An additional treatment used in 2012 included base fungicide treated seed with Thimet 20G applied in-furrow at 3.7 kg ha^{-1} with and without a foliar application of Orthene 97 at 0.36 kg ai ha^{-1}. Adult and immature thrips counts were taken at three, four, and five weeks after planting (WAP). Treatments with an Orthene foliar application and the imidacloprid seed treatment at three mg per seed, typically managed thrips better than other treatments. The commercial seed treatments without Orthene provided similar thrips control (thrips levels and plant damage assessments) and did not give control through the critical

thrips time interval of five WAP. The untreated check consistently had the highest thrips abundance. Yields were unaffected at three of four site-years; the imidacloprid seed treatment at 3 mg per seed increased lint yield compared to the untreated check at UCPRS in 2013.

INTRODUCTION

Thrips can be the most economically damaging pest complex due to its potential to cause severe maturity delay and yield loss (Reisig & Bacheler, 2014). Due to the potential for such losses and the cost of preventative control costs, North Carolina cotton growers annually spend more on thrips control than any other insect pest (Bacheler, unpub. data).

Since the end of production of aldicarb in 2010 (EPA, 2010), an effective at-planting, granular insecticide, typical thrips control practices subsequently included the use of an insecticidal seed treatments and a follow-up foliar application. Though the foliar application is recommended for thrips densities reaching economic threshold, the practice has become routine for the majority of North Carolina growers. Avicta Complete, containing the active ingredient thiamethoxam, and Acceleron N and Poncho/VOTiVO/Aeris, both containing imidacloprid are the most common insecticidal seed treatments used by growers on almost all of North Carolina cotton acres (Reisig & Bacheler, 2014).   All three of these seed treatments contain base fungicide treatments as well as a nematicide.

Research has shown that it is rare for thrips injury to cause yield loss in cotton in some areas of the Cotton Belt, while in some areas yield loss can be significant (Harp & Turner, 1976; Wilson et al., 2003). The cotton plant has the ability to recover from very severe thrips injury if growth conditions are favorable for late season plant compensation from early season thrips injury. Studies have shown that leaf area reduction of even 100% on seedling cotton will not affect yield when weather conditions are conducive for cotton growth (Wilson et al., 2003). It is theorized that the cotton plant compensates by allocating less energy on damaged leaves and relocating this energy to new upper leaves. Lower damaged leaves, especially those experiencing major cell death, complete cell expansion with fewer cells, which permits the expansion of new leaves to occur sooner (Lei & Wilson, 2004). Warm weather and adequate, timely moisture are key to cotton's ability to compensate for early season damage and stresses (Harp & Turner, 1976). In contrast, cool, wet weather can hinder the already injured plant's growth, causing maturity delays and yield loss.

The objective of this research was to screen thrips control methods to determine a grower's best options to reduce thrips population densities and optimize cotton lint yield.

MATERIALS AND METHODS

Trials were conducted at the Upper Coastal Plain Research Station (UCPRS) in Rocky Mount, NC and at the Tidewater Research Station (TRS) in Plymouth, NC. With the exception of early season thrips control, cotton was managed using recommended practices from the North Carolina Cooperative Extension Service.

Treatments were arranged in a randomized complete block design using four replications. Each plot was 3.7 m wide (four rows with 0.9 m row width) by 12 m long planted to 12.3 plants m^{-1} (134,492 plants ha^{-1}). The research was conducted on an Aycock very fine sandy loam at UCPRS in 2012 and 2013 and a Portsmouth fine sandy loam at TRS in 2012 and 2013. Phytogen 499 WRF (Dow AgroScience, Indianapolis, IN) was planted 1 May 2012 and 6 May 2013 at UCPRS and 9 May 2012 and 3 May 2013 at TRS.

All treatments consisted of a base fungicide seed treatment containing the fungicides fludioxynil (Maxim, Syngenta Crop Protection, Greensboro, NC) at 0.20 ml kg^{-1} seed, mefenoxam (Apron XL, Syngenta Crop Protection, Greensboro, NC) at 0.052 ml kg^{-1} seed, myclobutanil (Nuflow M, Wilbur-Ellis Agribusiness, Fresno, CA) at 1.138 ml kg^{-1} seed, and benzothiazole (Nusan 30, Wilbur-Ellis Agribusiness, Fresno, CA) at 0.813 ml kg^{-1} seed as well as the organophosphate insecticide, chlorpyrifos (Lorsban, Dow AgroSciences, Indianapolis, IN) at 0.065 ml kg^{-1} seed (Table 1). Treatments included an untreated check with base fungicide alone; Avicta Complete seed treatment (Syngenta Crop Protection, Greensboro, NC) containing the insecticide thiamethoxam at 0.375 mg/seed, the fungicide azoxystrobin at 0.03 mg/seed, and the nematicide abamectin at 0.15 mg/seed; Acceleron N seed treatment (Monsanto Company, St Louis, MO) containing the insecticide imidacloprid at 0.375 mg/seed and the nematicide thiodicarb at 0.375 mg/seed; and Poncho/VOTIVO/Aeris seed treatment (Bayer Crop Science, Research Triangle Park, NC) containing the insecticides clothianidin at 0.353 mg/seed and imidacloprid at 0.375 mg/seed and nematicides *Bacillus firmus* I-1582 at 0.07 mg/seed and thiodicarb at 0.375 mg/seed; base fungicide seed treated with imidacloprid as a seed treatment at eight times the labeled rate (8x rate of imidacloprid) at three mg per seed before planting (Aeris seed treatment contains imidacloprid applied at 0.375mg per seed); and the base fungicide seed treatment with an in-furrow application of Admire Pro (imidacloprid, Bayer Crop Science, Research Triangle Park, NC) at 621 ml ha^{-1}. The base fungicide seed treatment, Avicta Complete seed treatment, Acceleron N seed treatment, and the Poncho/VOTIVO/Aeris seed treatment were also included with a foliar application of Orthene 97 (acephate, AMVAC Chemical

Corporation, Los Angeles, CA) at 0.36 kg ai ha^{-1}. An additional treatment used in 2012 included base fungicide treated seed with Thimet 20G (phorate, AMVAC Chemical Corporation, Los Angeles, CA) in-furrow at 3.7 kg ha^{-1} with and without a foliar application of Orthene 97 at 0.36 kg ai ha^{-1}. Admire Pro was applied in-furrow with a CO_2 sprayer mounted to the planter, calibrated to deliver finished product at a rate of 82 l ha^{-1} at five km h^{-1} and 124 kPa using a single 8002 flat fan nozzle per row aligned parallel to the open furrow. The foliar applications were made using a CO_2 backpack sprayer calibrated to deliver finished product at 93 l ha^{-1} at five km h^{-1} and 345 kPa using a single Tee-Jet (Wheaton, IL), TX-10 hollow cone nozzle per row. All foliar applications were applied per extension recommendations at the first true leaf stage on 16 May 2012 and 24 May 2013 at UCPRS and 31 May 2012 and 22 May 2013 at TRS.

To quantify thrips abundance, samples were taken at three, four, and five after weeks after planting (WAP) by carefully cutting five plants per plot at the soil surface using a single-edged razor to minimize disturbance to plants and thrips. The cut plants were immediately placed into a pint or quart glass jar containing a soapy water solution for transport to the lab. Plants were washed onto a 270-mesh screen with 0.053 mm openings and any material retained was rinsed into vials of 70% alcohol solution for storage (Reisig & Godfrey, 2006). The material and solution was rinsed into a Petri-dish and adult and immature thrips were counted using a 0.7-3.0x dissecting Bausch and Lomb stereo-zoom dissecting microscope with 10x occulars. Adults were removed from the untreated check plots and later identified to species. The sampled plants were allowed to dry down for seven days at room temperature, at which time dry weights were recorded per five plant sample. At three WAP at TRS in 2012 and 2013, only plots without a foliar application were sampled because the foliar application had not yet been applied at the time of sampling.

At each sampling date, the number of true leaves, plant height, a visual thrips injury rating, and a visual vigor rating were also recorded for 10 plants throughout each plot. Leaves were counted as a true leaf when reaching the approximate area of a dime. Plant height was measured from the soil line to the terminal bud. Thrips damage ratings were based on a scale from one to five where a one is no damage and a five is near plant death (Faircloth et al., 2001). Vigor ratings give a visual rating of the health of seedlings in consideration of thrips damage. Vigor ratings were based on overall plant health taking into account the amount of thrips injury, plant height, approximate leaf area and overall plant size. Vigor ratings were based on a scale from one to five where a one is the healthiest plants with little thrips injury, the greatest plant heights, and large leaf areas while a five is the least vigorous plants with increased thrips injury, shorter plant heights, and little leaf area. Stand counts were taken each site year from a randomly selected three meter section on the two center rows of each plot after the critical thrips window (Leigh, 1995) so that any plant deaths due to thrips injury could be quantified.

The two center rows were harvested with a two row John Deere 9930 cotton picker equipped with a Rice Lake Weighing System Model 920i weight indicator with the Cotton Data Software package (Master Scales, Greenwood, MS) to determine seed cotton weight per plot. This value was converted to lint yield per acre based on a 0.40 seed cotton to lint conversion.

Data were subjected to analysis of variance (ANOVA) using the PROC GLM procedure in SAS 9.3 (SAS Institute Inc., Cary, North Carolina). Included in the model were year, location, treatment, and block. Interactions between year and treatment as well as location and treatment were observed. Each site-year was analyzed and is presented separately. Treatment means were separated using Fisher's Protected LSD test at $p \leq 0.05$. Thrips abundance was analyzed separately for total, adult, and immature thrips. Adult and immature thrips levels followed the same trends as total thrips and therefore not shown. PROC CORR (SAS Institute Inc., Cary, NC) was used to quantify the correlation between dry weights per five plants to thrips abundance using Pearson's correlation coefficients. Lint yield means were separated using Dunnett's multiple comparison (SAS Institute Inc., Cary, North Carolina) comparing all treatments to the untreated check at α=0.05.

RESULTS & DISCUSSION

Species Composition

Thrips populations at UCPRS included *Frankliniella occidentalis*, western flower thrips, *Frankliniella fusca*, tobacco thrips, and *Thrips tabaci*, onion thrips (Table 2). Western flower thrips was the dominant species accounting or almost 60% of the population over 2012 and 2013. Western flower thrips can be difficult to control. Additionally, some populations have developed resistance to many thrips insecticides (Eger et al., 1998; Espinosa et al., 2002; Jenson, 2000). Tobacco thrips accounted for about 25% of the population although it is generally considered the most common species in North Carolina cotton (Cho et al., 1995). Onion thrips was about 15% of the population and *Frankliniella* *tritici*, eastern flower thrips, and *Neohydatothrips variabilis*, soybean thrips, each accounted for one percent of the population at UCPRS.

Tobacco thrips accounted for 74% of the thrips population at TRS in Plymouth, NC. Onion thrips again accounted for about 15% and *F. tritici* and *N. variabilis* each accounted for about four percent of the population at TRS. Unlike UCPRS however, Western flower thrips only accounted for two percent of the population at TRS during 2012 and 2013.

Thrips Abundance

Though treatment interactions with location and year were found, trends were observed among several treatments which demonstrated more consistent thrips control across all site-years (Table 3). Acceleron N with Orthene, Avicta Complete with Orthene, and Poncho/VOTIVO/Aeris with Orthene, 8x rate of imidacloprid seed treatment, and Thimet with Orthene (only included in 2012) had the fewest thrips at 80% of the samples or more.

With the exception of five WAP at UCPRS 2013, when the untreated check had the fewest total thrips (Table 3), it had the most total thrips at all sampling dates. The commercially available seed treatments; Acceleron N, Avicta Complete, and Poncho/VOTIVO/Aeris; without Orthene were also inconsistent in reducing thrips densities. These three treatments each had at least one sampling date in which it had the most total thrips and another in which it had the fewest total thrips.

At UCPRS 2013, between four and five WAP a major, area wide thrips flight occurred (Table 3). At all other locations and dates, total thrips in a treatment exceeded an average 25 per plant only once. The lowest total count per plant recorded for the five WAP sample at UCPRS 2013 was 33 thrips and was recorded in the untreated check plot. Seven of ten treatments exceeded 40 thrips per plant and two treatments exceeded 70 total thrips per plant. Both treatments that exceeded 70 thrips per plant included Orthene. All of the treatments that did not include Orthene had fewer thrips at this date than the treatments that did include it. Across all other site-years, treatments without Orthene did not reduce thrips numbers as often as those treatments with it.

Dry Weight

With the exception of three WAP in 2013, there were differences among treatments for plant dry weights at UCPRS (Table 4). Avicta Complete with Orthene, Acceleron N with Orthene, Poncho/VOTIVO/Aeris with Orthene, and an 8x rate of imidacloprid seed treatment produced the highest dry weights at most of the sampling dates. The untreated check and Admire Pro in-furrow had the lowest dry weights at most of the sampling dates at UCPRS.

Treatment differences for dry weights were only observed at TRS in 2012 (Table 4). An 8x imidacloprid seed treatment and Avicta Complete without Orthene had the highest dry weights at all three sampling dates and Avicta Complete, Poncho/VOTIVO/Aeris, and Acceleron N seed treatments with Orthene were similar to an 8x rate of imidacloprid seed treatment and Avicta Complete without Orthene at both four and five WAP with the highest dry weights. The untreated check had the lowest dry weights at all sampling dates and the base fungicide with Orthene, Admire Pro in-furrow, Acceleron N without Orthene, and Poncho/VOTIVO/Aeris without Orthene were similar to the untreated check at four and five WAP with the lowest dry weights.

Inconsistent treatment differences were observed with the three commercial seed treatments without Orthene at both locations. Avicta Complete, Poncho/VOTIVO/Aeris, and Acceleron N without Orthene each had the lowest dry weights at one or more sampling dates (Table 4). The three seed treatments without Orthene also had the highest dry weights at one or more sampling dates.

Dry weights from the five WAP sample at UCPRS 2013 had a strong positive correlation with total thrips counts on the same sampling date (Table 5). This was the only sample that these two factors were positively correlated regardless of location or year. At five WAP, the efficacy of seed treatments have begun to decrease as well as the efficacy of Orthene foliar applications made two weeks prior (Reisig & Bacheler, 2014). Between four and five WAP at UCPRS in 2013, a large flight of thrips came into the field (Table 3). Treatments that consistently had the fewest thrips at other dates, such as an Avicta Complete with Orthene, Acceleron N with Orthene, and Poncho/VOTIVO/Aeris with Orthene, had the highest thrips densities at five WAP. These same treatments had the highest dry weights at most sampling dates (Table 4). These observations could indicate that the entering thrips may have been attracted to larger healthier plants, or have been attracted to plants with lower existing thrips densities to avoid competition as is described by Agrawal and Colfer (2000).

Thrips Injury Rating

Treatment differences were observed for thrips injury ratings at all sampling dates (Table 6). An 8x rate of imidacloprid seed treatment, Avicta Complete seed treatment with Orthene, and Acceleron N with Orthene had the best thrips injury ratings at more than 50%

of the sampling dates. The three commercially available seed treatments without Orthene were rated better than the untreated check at most sampling dates, but had more injury than the three treatments listed above. The untreated check, base fungicide with Orthene, and Admire Pro in-furrow received the worst ratings of all the treatments at greater than 50% of the sampling dates.

Number of True Leaves

There were differences among treatments for the number of true leaves at all sampling dates except for four and five WAP at UCPRS 2012 and during three and four WAP at TRS 2013 (Table 7). An 8x rate of imidacloprid seed treatment had the most true leaves or was similar to the treatment with most true leaves at all significant sampling dates. Avicta Complete with and without Orthene and Acceleron N with and without Orthene were similar to an 8x rate of imidacloprid seed treatment with the most true leaves at greater than 50% of the sampling dates.

The untreated check had the fewest true leaves at each sampling date and Admire Pro in-furrow was similar to the untreated check at all but one sampling date (Table 7). Base fungicide seed treatment with Orthene had more true leaves than the untreated check at all but one sampling date.

Plant Height

There were treatment differences for plant height at all sampling dates except for three WAP at TRS 2013 (Table 8). The tallest plants were found in plots receiving an 8x rate of imidacloprid seed treatment, Acceleron N seed treatment with and without Orthene, Avicta Complete seed treatment with Orthene, and Poncho/VOTIVO/Aeris seed treatment without Orthene. Plant heights in these treatments were similar to treatments with the tallest plants at 70% of the sampling dates or more (Table 8). The untreated check, Admire Pro in-furrow, and the base fungicide seed treatment with Orthene consistently had the shortest plants throughout all sampling dates.

Yield

Yields ranged from 1144 kg (untreated check, TRS 2013) to 1644 kg (Poncho/Votivo/Aeris seed treatment with an Orthene foliar application, UCPRS 2012; Table 9). No treatment differences were found at UCPRS 2012 and TRS 2012 and 2013. This is consistent with other studies, which also found no yield response to thrips management treatments (Harp & Turner, 1976; Wilson et al., 2003). At UCPRS 2013 the 8x rate of imidacloprid seed treatment was the only treatment the yielded better than the untreated check.

2012 at UCPRS and TRS offered optimal growing conditions, warm temperatures with timely moisture (Reddy et al., 1991), compared to a cool, wet spring brought by 2013. Both locations received more than 100 fewer DD60 heat units in May 2013 compared to May 2012 (Table 10) (CRONOS, 2013). These early season temperatures did not allow seedlings to grow off rapidly, as in 2012, giving seedlings a longer exposure period to thrips and thrips injury. This demonstrates the importance of early season thrips control, especially in years where optimal growing conditions are not present.

SUMMARY

All of the commercially-available seed treatments evaluated did not differ consistently in the parameters measured. Though an Orthene foliar application, when added to the above seed treatments did not increase yield on any plots, it did reduce thrips densities compared to the same seed treatments without Orthene.

Unlike the consistent thrips control found at the Wilson County site in 2012 and in 2013 (see Chapter II) , the Admire Pro in-furrow application via flat fan nozzles oriented with the row plus treated seed did not provide better thrips management than a number of the other treatments evaluated. This inconsistency of control could be due in part to the different application equipment used in each setting; this difference awaits further evaluation of the two delivery systems in the same tests under various weather and thrips abundance conditions.

An 8x rate of imidacloprid seed treatment was the only treatment to increase yield at either location in either year. This treatment, though not available for public use, gave the most consistent results across parameters than any of the other treatments.

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Table 1. Insecticide products evaluated in screening tests at UCPRS[z] and TRS[y] in 2012 and 2013.

Treatment	Insecticide	Fungicide[x]	Nematicide	Application
Untreated Check	-	-	-	-
Avicta Complete	thiamethoxam	azoxystrobin	abamectin	seed treatment
Poncho/ VOTIVO/ Aeris	imidacloprid/clothianidin	-	*Bacillus firmus* I-1582/thiodicarb	seed treatment
8x Rate of Imidacloprid	imidacloprid	-	-	seed treatment
Acceleron N	imidacloprid	-	thiodicarb	seed treatment
Admire Pro In-furrow	imidacloprid	-	-	in-furrow liquid
Thimet	phorate	-	-	in-furrow granular
Orthene	acephate	-	-	foliar

[z]UCPRS – Upper Coastal Plain Research Station, Rocky Mount, NC

Table 1 continued.

[y]TRS – Tidewater Research Station, Plymouth, NC

[x]Fungicide – All treatments included a base fungicide seed treatment, anything shown in the table is in addition

Table 2. Species composition of thrips populations found in four untreated check plots at three, four, and five weeks after planting by location and year.

	Thrips Species ------------------- Thrips per 20 plants -------------------				
Sample	***F. fusca*** [z]	***F. occidentalis*** [y]	***T. tabaci*** [x]	***F. tritici*** [w]	***N. variabilis*** [v]
UCPRS12 [u]					
3 WAP	7	13	15	1	0
4 WAP	4	4	1	0	0
5 WAP	8	10	3	2	5
UCPRS13 [t]					
3 WAP	31	111	16	1	0
4 WAP	11	16	5	0	0
5 WAP	17	35	11	1	0
TRS12 [s]					
3 WAP	49	1	8	1	0
4 WAP	7	1	0	2	0
5 WAP	14	1	14	2	0
TRS13 [r]					
3 WAP	6	0	0	0	1
4 WAP	17	0	0	0	5
5 WAP	42	1	9	1	1

[z] *Frankliniella fusca*, Tobacco thrips

[y] *Frankliniella occidentalis*, Western flower thrips

[x] *Thrips tabaci*, Onion thrips

[w] *Frankliniella tritici*, Eastern flower thrips

[v] *Neohydatothrips variabilis*, Soybean thrips

[u] UCPRS12 – Upper Coastal Plain Research Station 2012, Rocky Mount, NC

[t] UCPRS13 – Upper Coastal Plain Research Station 2013, Rocky Mount, NC

[s] TRS12 – Tidewater Research Station 2012, Plymouth, NC

[r] TRS13 – Tidewater Research Station 2013, Plymouth, NC

Table 3. Number of total thrips at three, four, and five weeks after planting per five plants.

Treatments	-----3 Weeks After Planting-----				-----4 Weeks After Planting-----				-----5 Weeks After Planting-----			
	UCPRS12[y]	UCPRS13[x]	TRS12[w]	TRS13[v]	UCPRS12	UCPRS13	TRS12	TRS13	UCPRS12	UCPRS13	TRS12	TRS13
Untreated Check	304 a[z]	110 a	90 a	26 a	53 a	73 abc	86 a	44 a	38 a	166 c	36 abc	36 a
Avicta Complete	116 b	65 cb	23 bc	9 bc	35 b	61 bcd	28 cd	18 bc	28 bc	216 bc	40 ab	22 bc
Poncho/ VOTIVO/ Aeris	116 b	46 cde	12 c	6 bc	23 cd	68 abc	15 de	13 cd	33 ab	177 bc	16 de	17 bc
8x Rate of Imidacloprid	75 bc	58 bcd	7 c	3 c	10 f	91 a	12 de	3 d	18 de	277 abc	11 de	14 c
Acceleron N	115 b	75 b	22 bc	4 c	31 bc	79 ab	45 b	14 c	33 ab	272 abc	43 a	19 bc
Admire Pro In-furrow	124 b	55 bcd	37 b	15 b	20 de	47 cde	34 bc	27 b	22 cd	172 c	21 cde	25 b
Thimet	50 c	-	24 bc	-	31 bc	-	23 cde	-	22 cd	-	26 bcd	-
Base fungicide-Orthene	48 c	35 de	-	-	15 def	31 e	27 cd	18 bc	20 cde	369 a	11 de	18 bc
Avicta Complete-Orthene	42 c	23 e	-	-	14 ef	36 ed	15 de	10 cd	26 bcd	286 abc	6 e	16 bc
Poncho/ VOTIVO/Aeris-Orthene	55 c	28 e	-	-	15 def	38 ed	8 e	11 cd	23 cd	365 a	7 e	18 bc
Acceleron N-Orthene	52 c	40 de	-	-	12 ef	35 ed	14 de	9 cd	21 cde	296 ab	6 e	17 bc
Thimet-Orthene	31 c	-	-	-	11 f	-	9 e	-	11 e	-	6 e	-
LSD[u]	51	23	17	9	8	27	16	10	10	122	16	10

Table 3 Continued.

[z]Means in the same column followed by the same letter are not significantly different

[y]UCPRS12 – Upper Coastal Plain Research Station 2012 Rocky Mount, NC

[x]UCPRS13 – Upper Coastal Plain Research Station 2013 Rocky Mount, NC

[w]TRS12 – Tidewater Research Station 2012 Plymouth, NC

[v]TRS13 – Tidewater Research Station 2013 Plymouth, NC

[u]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 4. Insecticide treatment differences in dry weights at three, four, and five weeks after planting.

	-----3 Weeks After Planting-----				-----4 Weeks After Planting-----				-----5 Weeks After Planting-----			
Treatments	UCPRS12[y]	UCPRS13[x]	TRS12[w]	TRS13[v]	UCPRS12	UCPRS13	TRS12	TRS13	UCPRS12	UCPRS13	TRS12	TRS13
	-- grams per plant --											
Untreated Check	0.176 d[z]	0.143	0.145 b	0.124	0.319 f	0.187 c	0.335 de	0.201	0.510 f	0.214 d	0.489 e	0.422
Avicta Complete	0.202 bcd	0.163	0.194 a	0.120	0.382 bcde	0.234 ab	0.387 abc	0.230	0.691 ef	0.241 cd	0.656 abcd	0.429
Poncho/ VOTIVO/ Aeris	0.198 bcd	0.143	0.193 a	0.119	0.372 cdef	0.227 b	0.316 e	0.180	0.805 cde	0.248 cd	0.541 de	0.365
8x Rate of Imidacloprid	0.211 abc	0.141	0.194 a	0.120	0.345 def	0.243 ab	0.407 abc	0.194	1.079 ab	0.342 b	0.706 abc	0.390
Acceleron N	0.220 ab	0.154	0.185 a	0.122	0.370 cdef	0.243 ab	0.357 cde	0.185	0.744 de	0.307 cb	0.543 cde	0.394
Admire Pro In-furrow	0.189 cd	0.141	0.182 a	0.121	0.370 cdef	0.179 c	0.369 bcde	0.180	0.762 de	0.219 d	0.640 abcde	0.343
Thimet	0.180 d	-	0.181 a	-	0.372 cdef	-	0.382 abcd	-	0.905 bcd	-	0.6632 abcd	-
Base fungicide-Orthene	0.204 bcd	0.155	-	-	0.339 ef	0.248 ab	0.326 de	0.194	0.753 de	0.422 a	0.622 bcde	0.414
Avicta Complete-Orthene	0.216 abc	0.155	-	-	0.433 ab	0.266 a	0.435 a	0.217	0.996 abc	0.430 a	0.787 a	0.472
Poncho/ VOTIVO/Aeris-Orthene	0.204 bcd	0.188	-	-	0.416 abc	0.250 ab	0.400 abc	0.199	1.161 a	0.440 a	0.724 ab	0.402
Acceleron N-Orthene	0.236 a	0.155	-	-	0.443 a	0.253 ab	0.425 ab	0.208	0.909 bcd	0.485 a	0.657 abcd	0.429
Thimet-Orthene	0.199 bcd	-	-	-	0.400 abcd	-	0.359 cde	-	1.007 abc	-	0.516 de	-
LSD[u]	0.031	NS	0.26	NS	0.057	0.039	0.65	NS	0.215	0.079	0.163	NS

Table 4 Continued.

[z]Means in the same column followed by the same letter are not significantly different

[y]UCPRS12 – Upper Coastal Plain Research Station 2012 Rocky Mount, NC

[x]UCPRS13 – Upper Coastal Plain Research Station 2013 Rocky Mount, NC

[w]TRS12 – Tidewater Research Station 2012 Plymouth, NC

[v]TRS13 – Tidewater Research Station 2013 Plymouth, NC

[u]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 5. Correlation coefficients between plant dry weight and thrips abundance at three, four, and five weeks after planting for UCPRS and TRS in 2012 and 2013.

Sample	UCPRS12[z]	UCPRS13[y]	TRS12[x]	TRS13[w]
3 WAP	-0.141	0.138	-0.686*	0.134
4 WAP	-0.330*	-0.098	-0.209	0.068
5 WAP	-0.279	0.671*	0.197	-0.087

* Coefficients are significant at $p \leq 0.05$ according to Pearson's correlations.

[z] UCPRS12 – Upper Coastal Plain Research Station 2012 Rocky Mount, NC

[y] UCPRS13 – Upper Coastal Plain Research Station 2013 Rocky Mount, NC

[x] TRS12 – Tidewater Research Station 2012 Plymouth, NC

[w] TRS13 – Tidewater Research Station 2013 Plymouth, NC

Table 6. Insecticide treatment differences in thrips injury rating at three, four, and five weeks after planting.

	-----3 Weeks After Planting-----				-----4 Weeks After Planting-----				-----5 Weeks After Planting-----			
Treatment	UCPRS12[y]	UCPRS13[x]	TRS12[w]	TRS13[v]	UCPRS12	UCPRS13	TRS12	TRS13	UCPRS12	UCPRS13	TRS12	TRS13
Untreated Check	3.44 a[z]	3.29 a	3.07 a	2.73 a	4.00 a	3.81 a	3.38 a	3.16 a	3.26 a	3.58 a	3.59 a	3.54 a
Avicta Complete	2.80 c	2.95 cde	2.26 d	2.03 c	3.25 bcd	3.49 b	1.98 e	1.89 de	2.69 b	2.90 bc	2.32 e	2.26 d
Poncho/ VOTIVO/ Aeris	2.83 c	3.14 ab	2.20 d	2.38 b	3.13 bcde	3.21 c	1.94 ef	2.14 cd	2.47 c	2.64 cd	2.26 e	2.40 d
8x Rate of Imidacloprid	2.17 f	2.79 e	1.92 e	2.20 bc	2.56 ef	2.99 d	1.74 f	1.88 de	2.03 de	2.43 de	1.66 g	1.66 g
Acceleron N	3.00 b	3.03 bcd	2.51 c	2.26 b	3.56 ab	3.54 b	2.31 d	2.15 cd	2.76 b	2.88 bc	2.64 d	2.38 d
Admire Pro In-furrow	2.72 cd	2.86 ed	2.56 c	2.58 a	3.50 abc	3.50 b	2.71 c	2.79 b	2.51 c	2.98 b	3.09 b	3.26 b
Thimet	2.75 cd	-	2.71 b	-	2.94 cdef	-	2.80 c	-	2.47 c	-	2.58 d	-
Base fungicide-Orthene	3.10 b	3.24 a	-	-	3.31 bcd	2.24 f	3.32 a	3.05 ab	2.45 c	2.10 e	2.92 c	3.00 c
Avicta Complete-Orthene	2.75 cd	2.81 e	-	-	2.75 def	2.30 f	2.38 d	1.79 e	2.08 d	1.65 f	2.00 f	1.81 fg
Poncho/ VOTIVO/Aeris -Orthene	2.57 e	3.04 bc	-	-	2.44 f	2.50 e	2.26 d	2.33 c	1.93 ef	1.65 f	1.95 f	2.06 e
Acceleron N-Orthene	2.63 ed	2.86 ed	-	-	2.38 f	2.18 f	2.22 d	1.91 de	2.06 de	1.74 f	2.02 f	1.89 ef
Thimet-Orthene	2.65 ed	-	-	-	2.75 def	-	3.03 b	-	1.86 f	-	2.30 e	-
LSD[u]	0.12	0.17	0.14	0.19	0.58	0.19	0.21	0.34	0.13	0.34	0.13	0.19

Table 6 Continued.

[z]Means in the same column followed by the same letter are not significantly different

[y]UCPRS12 – Upper Coastal Plain Research Station 2012 Rocky Mount, NC

[x]UCPRS13 – Upper Coastal Plain Research Station 2013 Rocky Mount, NC

[w]TRS12 – Tidewater Research Station 2012 Plymouth, NC

[v]TRS13 – Tidewater Research Station 2013 Plymouth, NC

[u]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 7. Insecticide treatment differences in number of true leaves at three, four, and five weeks after planting.

Treatment	-----3 Weeks After Planting-----				-----4 Weeks After Planting-----				-----5 Weeks After Planting-----			
	UCPRS12[y]	UCPRS13[x]	TRS12[w]	TRS13[v]	UCPRS12	UCPRS13	TRS12	TRS13	UCPRS12	UCPRS13	TRS12	TRS13
Untreated Check	1.31 h[z]	1.65 bcd	1.51 c	1.48	4.68	2.76 d	1.96 d	2.11	5.95	5.73 d	4.89 e	4.61 c
Avicta Complete	1.78 cde	1.80 a	1.89 ab	1.59	4.91	3.89 a	2.24 bc	2.54	6.31	6.28 abc	5.04 cde	4.86 bc
Poncho/ VOTIVO/ Aeris	1.63 fg	1.55 d	1.89 ab	1.55	4.91	2.93 cd	2.31 ab	2.33	6.13	5.53 d	5.31 abc	4.86 bc
8x Rate of Imidacloprid	1.98 a	1.75 ab	1.99 a	1.58	4.65	3.51 abc	2.45 a	2.50	5.86	6.23 abc	5.43 a	5.05 ab
Acceleron N	1.59 g	1.70 abc	1.79 b	1.55	4.94	3.29 abcd	2.18 bc	2.38	6.11	6.30 ab	5.21 abc	5.00 ab
Admire Pro In-furrow	1.75 def	1.55 d	1.81 b	1.50	4.75	3.04 bcd	2.11 c	2.53	6.30	5.61 d	5.08 cde	4.61 c
Thimet	1.94 ab	-	1.85 b	-	4.68	-	2.26 b	-	6.19	-	5.38 ab	-
Base fungicide-Orthene	1.70 efg	1.60 cd	-	-	4.73	3.71 ab	2.11 c	2.31	6.15	6.36 a	5.36 ab	5.23 a
Avicta Complete-Orthene	1.90 abc	1.79 a	-	-	4.74	3.20 abcd	2.24 bc	2.45	6.18	6.05 c	5.18 abcd	4.89 bc
Poncho/ VOTIVO/Aeris -Orthene	1.86 abcd	1.73 ab	-	-	4.51	3.78 a	2.30 b	2.34	6.00	6.06 bc	4.91 de	4.88 bc
Acceleron N-Orthene	1.83 bcde	1.73 ab	-	-	4.73	3.70 ab	2.29 b	2.36	6.31	6.41 a	5.43 a	4.84 bc
Thimet-Orthene	1.90 abc	-	-	-	4.75	-	2.18 bc	-	6.29	-	5.14 bcde	-
LSD[u]	0.13	0.12	0.13	-	-	0.70	0.14	-	-	0.24	0.28	0.28

Table 7 Continued.

[z]Means in the same column followed by the same letter are not significantly different

[y]UCPRS12 – Upper Coastal Plain Research Station 2012 Rocky Mount, NC

[x]UCPRS13 – Upper Coastal Plain Research Station 2013 Rocky Mount, NC

[w]TRS12 – Tidewater Research Station 2012 Plymouth, NC

[v]TRS13 – Tidewater Research Station 2013 Plymouth, NC

[u]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 8. Insecticide treatment differences in plant height (cm) at five weeks after planting.

	--------------------------cm--------------------------			
Treatment	UCPRS12[y]	UCPRS13[x]	TRS12[w]	TRS13[v]
Untreated Check	11.65 e[z]	8.59 h	12.63 f	10.35 d
Avicta Complete	14.19 d	11.49 e	14.86 abc	11.18 a
Poncho/ VOTIVO/ Aeris	14.96 bc	9.88 f	15.16 a	11.09 ab
8x Rate of Imidacloprid	15.13 bc	12.08 cd	14.78 abc	10.73 abcd
Acceleron N	13.96 d	11.76 de	14.64 abc	10.91 abc
Admire Pro In-furrow	14.44 cd	9.33 g	14.18 cde	10.49 cd
Thimet	14.48 cd	-	14.46 abcd	-
Base fungicide-Orthene	14.05 d	12.53 bc	13.53 e	10.60 bcd
Avicta Complete-Orthene	16.08 a	12.89 b	15.01 ab	11.24 a
Poncho/ VOTIVO/Aeris-Orthene	15.33 b	12.73 b	14.24 cde	11.00 abc
Acceleron N-Orthene	16.13 a	13.56 a	14.36 bcd	10.89 abc
Thimet-Orthene	16.17 a	-	13.75 de	-
LSD[u]	0.69	0.50	0.71	0.52

[z]Means in the same column followed by the same letter are not significantly different

[y]UCPRS12 – Upper Coastal Plain Research Station 2012 Rocky Mount, NC

[x]UCPRS13 – Upper Coastal Plain Research Station 2013 Rocky Mount, NC

[w]TRS12 – Tidewater Research Station 2012 Plymouth, NC

[v]TRS13 – Tidewater Research Station 2013 Plymouth, NC

[u]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 9. Insecticide treatment differences in lint yield at Rocky Mount and Plymouth in 2012 and 2013.

Treatments	Yield -----------------------------------kg lint ha^{-1}-------------------------------			
	UCPRS12[y]	UCPRS13[x]	TRS12[w]	TRS13[v]
Untreated Check	1448	1351	1478	1144
Avicta Complete	1465	1444	1458	1336
Poncho/VOTIVO/Aeris	1472	1355	1514	1406
8x Rate of Imidacloprid	1499	1653[z]	1510	1338
Acceleron N	1506	1541	1362	1585
Admire Pro (in-furrow)	1466	1398	1408	1438
Thimet	1495	-	1418	-
Untreated Check – Orthene	1584	1485	1464	1309
Avicta Complete – Orthene	1538	1456	1444	1392
Poncho/VOTIVO/Aeris – Orthene	1665	1590	1428	1419
Acceleron N – Orthene	1561	1555	1286	1357
Thimet - Orthene	1641	-	1301	-
DSD[u]	311	267	323	690

Table 9 continued.

[z]Treatments differ in yield response from the untreated check

[y]UCPRS12 – Upper Coastal Plain Research Station 2012 Rocky Mount, NC

[x]UCPRS13 – Upper Coastal Plain Research Station 2013 Rocky Mount, NC

[w]TRS12 – Tidewater Research Station 2012 Plymouth, NC

[v]TRS13 – Tidewater Research Station 2013 Plymouth, NC

[u]DSD – Value of least significant difference according to Dunnett's multiple comparison test at $P \leq 0.05$

Table 10. Accumulated heat units (DD60) per month from April to September for each site-year.[z]

Month	UCPRS12[y]	UCPRS13[x]	TRS12[w]	TRS13[v]
	----------DD60----------			
April	2.3	27.6	-22.8	-20.3
May	344.9	234.2	325.1	218.9
June	421.2	471.5	412.5	479
July	645.1	580.4	647.9	588.5
August	522.2	481.8	531.5	488.8
September	307.3	291.4	319.1	283.3
Total	2243	2086.9	2213.3	2038.2

[z] CRONOS database - State climate office of North Carolina. 2013. Retrieved 12 December 2013 from http://www.nc-climate.ncsu.edu/cronos.

[y]UCPRS12 – Upper Coastal Plain Research Station 2012 Rocky Mount, NC

[x]UCPRS13 – Upper Coastal Plain Research Station 2013 Rocky Mount, NC

[w]TRS12 – Tidewater Research Station 2012 Plymouth, NC

[v]TRS13 – Tidewater Research Station 2013 Plymouth, NC

IMPACT OF COTTON PLANTING DATE ON THRIPS POPULATION DENSITIES IN UPPER SOUTHEAST

IMPACT OF COTTON PLANTING DATE ON THRIPS POPULATION DENSITIES IN UPPER SOUTHEAST

Todd A. Spivey

Jack S. Bacheler

Keith L. Edmisten

North Carolina State University

Raleigh, NC

Dominic D. Reisig

North Carolina State University

Plymouth, NC

ABSTRACT

North Carolina cotton is generally planted late April through mid-May depending upon soil temperatures and predicted weather in the following week based upon extension recommendations. Growers also plant in late April to 25 May to remain eligible for federal crop insurance. The final planting date for cotton insurance coverage was changed in 2014, to 25 May, with a five day grace period. With growers able to extend their planting date later into the month of May, it is important to understand how this change will affect insect pressure on cotton growth and yield. Timing of thrips pressure on cotton seedlings can vary based on weather as well as availability of other suitable hosts. Thrips generally move into spring hosts, such as cotton seedlings, as winter hosts begin to senesce. The objective of this research was to evaluate the impact of several planting dates on thrips densities. This study included a recommended planting date and a late planting date in 2012 and an early, recommended, and late planting date in 2013. Included in each planting date was an untreated check with a commercially applied base fungicide seed treatment, thiamethoxam seed treatment alone (with the same base fungicide as the check), and thiamethoxam seed treatment (with the same base fungicide as the check) with a foliar application of acephate. Field design was a randomized complete block in 2012 and a split plot design in 2013 with four replications. Thrips counts were taken at three, four, and five weeks after planting. With the exception of five weeks after planting in 2012, the recommended planting date had the most total and immature thrips. In 2013 when an early planting date was added, the early planting date had the fewest total and immature thrips at all sampling dates. Thiamethoxam seed treatment alone and thiamethoxam seed treatment with acephate had the fewest total and

immature thrips. In 2012, cotton planted according to extensions recommendations had greater yields than late planted cotton regardless of insecticide treatment, even though the recommended planted plots had greater thrips densities. In 2013, the recommended planted thiamethoxam seed treatment alone and thiamethoxam seed treatment with acephate, and the early planted thiamethoxam with acephate had the greatest yield. The late planted cotton had the lowest yields in 2013. Due to the higher yields compared to the early and late plant dates, growers should aim to plant cotton according to extension recommendations, early to mid-May, regardless of thrips densities.

INTRODUCTION

Cotton plant dates vary in North Carolina, but can begin as early as 15 April through 31 May. Optimum planting conditions are when soil temperatures reach 18° by 10 AM and when warm, dry weather is expected for the next several days (Edmisten, 2014). Cotton germinates best when temperatures are above 21° and can be hindered by continuous temperatures below 15°. Yields begin to decline rapidly after 10 June due to shortening the growing season (Edmisten, 2014); thus planting should be done no later than 31 May to ensure growers have time for a successful replant if necessary. Planting decisions are also defined by federal crop insurance guidelines. The final planting date for North Carolina cotton was changed in 2014 from 15 May to 25 May. Growers will then have a five day late period in which one percent of the crop insurance coverage is reduced for each day after the 25th (Yeatts, 2014).

Previous research has shown that planting date has a significant effect on thrips abundance in cotton (Parajulee et al., 2006; Parrella & Lewis, 1997). Late planted cotton generally hosts fewer thrips than a timely planted crop, possibly because other suitable, alternative hosts are more available later in the year (Parajulee et al., 2006) and because migrating adults thrips populations have often declined (Bacheler, pers. com.). However, planting late is generally not always a feasible option for growers. Especially for growers with large acreage, planting decisions are not made based on thrips management, but rather on temperature and the amount of time available to plant their crop (Edmisten, 2014; Leigh, 1995)

Though growers may not completely base planting decisions upon thrips management, it is important that the impact of planting date on thrips densities and management is better understood. The objective of this research is to evaluate the impact of planting date on thrips densities in the Southeast cotton belt.

MATERIALS AND METHODS

Trials were conducted at the Upper Coastal Plain Research Station (UCPRS) in Rocky Mount, NC. Phytogen 499 WRF (Dow AgroScience, Indianapolis, IN) was planted on an Aycock very fine sandy loam in 2012 and 2013. With the exception of planting date and thrips control methods, cotton was managed using the North Carolina Cooperative Extension Service recommended practices.

Treatments were arranged in a randomized complete block in 2012 with four replications. Plots were 3.7 m wide (four rows with 0.9 m row width) by 12 m long and planted to 12.3 plants m^{-1} (134,492 plants ha^{-1}). In 2013, treatments were placed in a split plot design with planting date as the main plots and insecticide treatment as the subplot with four replications. Main plots were 3.7 m wide by 43 m long. Each insecticide treatment was assigned to a 3.7 m wide by 12 m long subplot within each main plot.

Plant dates for 2012 included a recommended date, 7 May, and a later plant date, 23 May. In 2013 an early plant date was added to the treatments to include 30 April (early), 14 May (recommended), and 28 May (late).

Insecticide treatments included an untreated check with base fungicide seed treatment containing the fungicides fludioxynil (Maxim, Syngenta Crop Protection, Greensboro, NC) at

0.20 ml kg^{-1} seed, mefenoxam (Apron XL, Syngenta Crop Protection, Greensboro, NC) at 0.052 ml kg^{-1} seed, myclobutanil (Nuflow M, Wilbur-Ellis Agribusiness, Fresno, CA) at 1.138 ml kg^{-1} seed, and benzothiazole (Nusan 30, Wilbur-Ellis Agribusiness, Fresno, CA) at 0.813 ml kg^{-1} seed as well as the organophosphate insecticide, chlorpyrifos (Lorsban, Dow AgroSciences, Indianapolis, IN) at 0.065 ml kg^{-1} seed; commercially applied thiamethoxam seed treatment (Syngenta Crop Protection, Greensboro, NC) containing the insecticide thiamethoxam at 0.375 mg/seed, the fungicide azoxystrobin at 0.03 mg/seed, and the nematicide abamectin at 0.15 mg/seed; and thiamethoxam seed treatment with foliar acephate (Orthene 97, AMVAC Chemical Corporation, Los Angeles, CA) at 0.36 kg ai ha^{-}1, applied at the first true leaf stage.

The acephate foliar application was made using a CO_2 backpack sprayer calibrated to deliver finished product at 93 l ha^{-1} at five km h^{-1} and 345 kPa using a single Tee-Jet (Wheaton, IL), TX-10 hollow cone nozzle per row. In 2012, acephate was applied per extension recommendations at the first true leaf stage on 29 May for the recommended plant date and on 13 June for the late plant date. Acephate was applied in 2013 on 21 May for the early plant date, 4 June for the recommended plant date, and 18 June for the late plant date.

To quantify thrips abundance, samples were taken at three, four, and five after weeks after planting (WAP) by cutting five plants per plot at the soil surface using a straight razor to minimize disturbance to plants and thrips. The cut plants were immediately placed in a glass jar containing a soapy water solution for transport to the lab. Plants were washed onto a 270-mesh screen with 0.053 mm openings and any material retained was rinsed into vials of 70% alcohol solution for storage (Reisig & Godfrey, 2006). The material and solution was rinsed into a dish and thrips abundance was determined using a Bausch and Lomb 0.7 - 3.0 dissecting microscope with 10x occulars. Thrips immatures and adults were counted and recorded; adults were removed and identified by species from the untreated check plots. The sampled plants were allowed to dry down for seven days at room temperature, at which time dry weights were recorded per five plant sample.

At each sampling date, the number of true leaves, plant height, thrips injury rating, and vigor rating were also recorded for 10 plants throughout each plot. Leaves were counted as a true leaf when reaching the approximate area of a dime. Plant height was measured in cm and was measured from the soil line to the terminal bud. Thrips injury ratings were based on a scale from one to five, where one is no injury and five is near plant death (Faircloth et al., 2001). Vigor ratings give a visual rating of the health of seedlings in consideration of thrips damage. Vigor ratings were based on overall plant health taking into account the amount of thrips injury, plant height, approximate leaf area and overall plant size. Vigor ratings were based on a scale from one to five where a one is the healthiest plants with little thrips injury, the greatest plant heights, and large leaf areas while a five is the least vigorous plants with increased thrips injury, shorter plant heights, and little leaf area. Stand counts were taken at each site-year from a randomly selected three m section on the two center rows of each plot. Data and samples taken at three WAP in 2013 did not include any plots that included a foliar application of acephate because this sample date was also the spray date.

The two center rows were harvested with a two row John Deere 9930 cotton picker equipped with a Rice lake Weighing System Model 920i weight indicator with Cotton Data

Software package (Master Scales, Greenwood, MS) to determine seed cotton weight per plot. This value was converted to lint yield per acre based on 0.40 seed cotton to lint conversion.

Trials conducted in 2012 and 2013 used different experiment designs and therefore were analyzed separately based on their need for different error terms and will be presented as such. Data were subjected to analysis of variance using the PROC GLM procedure in SAS 9.3 (SAS Institute Inc., Cary, North Carolina). Included in both models were the independent variables; treatment, plant date, and block. In 2013, the interaction between block and plant date was used to test for differences by the main plot factor, plant date. Treatment means were separated using Fisher's Protected LSD test at $P \leq 0.05$.

RESULTS & DISCUSSION

Species Distribution

The two major species found at UCPRS in 2012 and 2013 were *Frankliniella occidentalis*, western flower thrips, and *Frankliniella fusca*, tobacco thrips (Table 1). Western flower thrips accounted for 58% of all thrips collected across both years unlike other studies showing that tobacco thrips generally dominate populations in the Southeast (Cho et al., 1995; Osekre et al., 2009). Western flower thrips are major pests because they can be more difficult to control with insecticides and also have the ability to develop resistance easily, especially when singular modes of action are used repeatedly (Eger et al., 1998; Espinosa et al., 2002; Jenson, 2000). Tobacco thrips accounted for about 36% of the sampled population, *Thrips tabaci* (onion thrips) five percent, and *Frankliniella tritici* (eastern flower thrips) and *Neohydatothrips variabilis* (soybean thrips) each accounted for approximately two percent of the population.

Thrips Abundance

An interaction was present at three WAP in 2013 between the main effects of plant date and thrips control treatment (Table 2). The lowest densities of total and immature thrips were found on plants in plots planted early, regardless of insecticide treatment. The highest densities were found in plots with the untreated check planted both at the recommended plant date and late plant date.

Differences were observed in plant dates for adult (Table 3), total (Table 4), and immature (Table 5) thrips abundance at all other sampling dates. In 2013, the recommended planted plots had the most adult thrips at four WAP, and the early planted plots had the most adult thrips at five WAP. The recommended plant date had the most total (Table 4) and immature (Table 5) thrips at all sampling dates except for five WAP in 2012 as is consistent with previous research stating that late plantings have reduced thrips pressure (Parajulee et al., 2006). The late planting date had the fewest thrips at three and four WAP in 2012 and at five WAP in 2013. Though only included in 2013, the early plant date had the fewest total and immature thrips at all sampling dates except for total thrips densities at five WAP. In the spring of 2013, cool, wet conditions in May and June slowed seedling grow-off, but also kept thrips populations low through the five WAP sample of the early planted date.

The untreated check plots had the most total (Table 6) and immature (Table 7) thrips at all sampling dates in 2012 and four and five WAP in 2013. Thiamethoxam seed treatment with acephate had the fewest total and immature thrips at all sampling dates in 2012 and four and five WAP in 2013. Thiamethoxam seed treatment alone was similar to the untreated check with the most thrips at three of six total sampling dates. Thiamethoxam seed treatment alone was also similar to thiamethoxam seed treatment with acephate with the fewest thrips at two sampling dates. Insecticide treatment differences were also observed with adult thrips following the same trends as total and immature thrips by insecticide treatment (data not shown).

Dry Weight

An interaction was found between the two main effects of planting date and thrips control treatment at four WAP in 2012 and five WAP in 2013. At four WAP in 2012, the recommended planting date had the greatest dry weights per plant regardless of insecticide treatment, ranging from 0.45 g per plant to 0.652 g per plant. Plots planted at the late date with thiamethoxam seed treatment with acephate had the lowest dry weight per plant at 0.406 g per plant.

At five WAP in 2013 the early planting date gave the lowest dry weights per five plants regardless of insecticide treatment. The recommended planting date planted with thiamethoxam seed treatment with acephate had the greatest dry weight per plant.

Plant date differences were observed in plant dry weights at all sampling dates except for three WAP in 2012 (Table 8). In 2012, the recommended planting date had the greatest dry weights per plant and in 2013 the recommended plant date and late plant date had the greatest dry weights per plant. In 2013, the recommended plant date had almost three times the dry weight per plant than that of the early plant date at all sampling dates. The increased dry weights at the recommended and late plant dates were likely due to warmer temperatures at planting than the cool temperatures observed at the early plant date.

Insecticide treatment differences were also observed at all sampling dates except for three WAP in 2012. The untreated check with base fungicide seed treatment had the lowest dry weight per plant at all sampling dates in 2012 and 2013. Thrips injury from feeding on plants found in the untreated check plots caused reduction in leaf area and stunting of plants. The feeding resulted in an overall reduction of plant biomass. Thiamethoxam seed treatment and thiamethoxam seed treatment with an acephate foliar application were similar with the greatest dry weights per plant at all sampling dates.

Thrips Injury Rating

A significant interaction between the main effects of plant date and insecticide seed treatment, for thrips injury rating, was observed at all sampling dates with the exception of three WAP in 2012 (Table 9). The untreated checks planted at both the recommended plant date and the late plant date in 2012 had the most thrips injury. Thiamethoxam seed treatment with and without acephate at the late plant date were similar with the least injury from thrips at all samples in 2012.

Early planted thiamethoxam seed treatment had the least thrips injury at three WAP in 2013. The untreated check at the recommended plant date had the most injury at three WAP in 2013. Thiamethoxam seed treatment with acephate at the late plant date had the least thrips injury at four WAP in 2013 while the untreated check at the early and recommended plant dates had the most thrips injury.

At five WAP, the untreated check at the early plant date had the most thrips injury. Regardless of insecticide treatment, the early planting date had more injury than most of the other treatments at five WAP (Table 9). It is likely that the early plant date had more injury than other treatments even though it had the fewest thrips present, because the seedlings grew-off slowly due to cool temperatures. Minor thrips feeding can cause severe injury to plants that are growing slowly (Leigh, 1995). Thiamethoxam seed treatment with acephate had the least thrips injury at five WAP in 2013.

Plant Height

Plant date (Table 10) and insecticide treatment (Table 11) differences were observed in plant height at four and five WAP in 2012. The tallest plants were found in plots planted at the recommended plant date at four and five WAP. Thiamethoxam seed treatment with acephate and thiamethoxam seed treatment were similar, ranging from 18.00 cm – 18.25 cm at five WAP. The plants from these plots were the tallest plants at both sampling dates. Plants from the untreated check plots had a mean height of 15.7 cm at five WAP.

An interaction between the main effects of plant date and insecticide treatment was observed at all sampling dates for plant height in 2013 (Table 12). At all sampling dates, the early plant date plots had the shortest plants regardless of insecticide treatment. Plants within the early plant date plots with the untreated check were the shortest plants at all 2013 sampling dates.

At three WAP, the tallest plants were observed in plots treated with thiamethoxam seed treatment at the recommended plant date. At four WAP, plants treated with thiamethoxam seed treatment with acephate at the recommended plant date, and thiamethoxam seed treatment with and without acephate at the late plant date, had the tallest plant heights. Plants treated with thiamethoxam seed treatment with acephate at the recommended planting date had the tallest planting heights at five WAP.

Number of True Leaves

In 2012, plant date (Table 10) and insecticide treatment (Table 11) differences were observed at four and five WAP. The recommended planting date had the most true leaves at all four and five WAP. At four WAP, the recommended planted plots had almost two more true leaves per plant than the late planted plots. At five WAP in 2012, the untreated check and thiamethoxam seed treatment were similar with the most true leaves at approximately six true leaves per plant, and thiamethoxam seed treatment with acephate had the fewest true leaves.

An interaction was found between planting date and insecticide treatment at three and four WAP in 2013 (Table 12). At three WAP, the recommended plant date with thiamethoxam seed treatment had the most true leaves with two true leaves per plant. The early planted untreated check had the fewest true leaves at one per plant. At four WAP, thiamethoxam seed treatment with acephate at the recommended plant date had the most true leaves at four WAP in 2013 with five true leaves per plant. All treatments planted early had the fewest true leaves with two true leaves per plant at four WAP.

Yield

In 2012, yields differed according to the main effect of plant date. Plots planted at the recommended plant date averaged 1412 kg lint ha^{-1} compared to 1327 kg lint ha^{-1} averaged by plots at the late plant date. No yield differences were observed for insecticide treatment in 2012.

An interaction was found between planting date and insecticide treatment in 2013 (Table 13). Thiamethoxam seed treatment with and without acephate planted at the recommended plant date and thiamethoxam seed treatment with acephate at the early plant date were all similar and yielded the most, ranging from 1369 to 1406 kg lint ha^{-1}. The highest yielding late planted plot was treated with thiamethoxam seed treatment with acephate, and yielded only 1024 kg lint ha^{-1}. The plots with the lowest yields included the untreated checks at the early and late plant date as well as thiamethoxam seed treatment at the late plant date. These plots produced yields ranging from 890 to 971 kg lint ha^{-1}.

Unlike 2012, yields were increased in plots with an insecticidal seed treatment in 2013. The 2013 growing season did not offer good conditions for late season compensation as did 2012 (Reddy et al., 1991), therefore, early season thrips control showed a greater effect in 2013. In 2013, Rocky Mount, NC had an uncharacteristically cool spring with excessive rainfall. Rocky Mount received 25.4 cm of rain in June 2013 alone compared to 5 cm in 2012 (Table 14) (CRONOS, 2013). May 2013 received over 100 heat units fewer than May 2012 (CRONOS, 2013). The excess rain, cloudy weather associated with the rain, and lack of heat likely delayed plant maturity considerably when compared to recent years, which would reduce the plant's ability of the untreated check and thiamethoxam seed treatment plots to compensate for early season thrips damage.

SUMMARY

Even though the recommended plant date had the greatest thrips abundance at most sampling dates regardless of insecticide treatment in both 2012 and 2013, this plant date appears most optimal for cotton growers in the upper Southeast. The recommended plant date had higher yields than other plant dates across insecticide treatments, likely due to factors relating to weather and season length. The late plant date produced the lowest yield in most cases and should be used cautiously by growers. Even though late planted cotton may have lower thrips densities, this did not translate into increased yields under the studied conditions.

Insecticide treatment differences for yield were only observed in 2013 likely due to excess rains and reduced heat units in the early part of the growing season. Having an added insecticide treatment increased yields compared to the untreated check. Especially at the optimal, recommended plant date, the impact of using acephate as a foliar insecticide treatment for management of thrips can be negligible and should only be recommended in thrips density threshold situations, as it did not always increase yields.

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Table 1. Species distribution of the thrips population found in four untreated check plots at three, four, and five weeks after planting by planting date and year.

	Thrips Species									
	Thrips per 20 plants									
	2012					2013				
Sample	***Ffus*** [z]	***Focc*** [y]	***Ttab*** [x]	***Ftri*** [w]	***Nvar*** [v]	***Ffus***	***Focc***	***Ttab***	***Ftri***	***Nvar***
Early										
3 WAP	-	-	-	-	-	11	47	0	0	0
4 WAP	-	-	-	-	-	21	25	5	0	1
5 WAP	-	-	-	-	-	33	33	2	0	0
Recommended										
3 WAP	6	7	2	0	0	35	43	7	0	0
4 WAP	6	1	1	0	1	42	69	6	0	0
5 WAP	5	6	1	10	0	8	32	0	0	0
Late										
3 WAP	5	4	0	0	0	57	81	4	0	0
4 WAP	4	9	1	2	0	2	10	2	0	0
5 WAP	8	12	0	1	0	2	17	0	0	0

[z] *Frankliniella fusca*, tobacco thrips

[y] *Frankliniella occidentalis*, western flower thrips

[x] *Thrips tabaci*, onion thrips

[w] *Frankliniella tritici*, eastern flower thrips

[v] *Neohydatothrips variabilis*, soybean thrips

Table 2. Effects of the interaction between plant date and insecticide treatment on immature and total thrips abundances at three weeks after planting in 2013.

	2013 – 3 WAP	
Interaction	**Immature**	**Total**
Early – Untreated Check	6 d[z]	20 d
Recommended – Untreated Check	105 ab	126 ab
Late – Untreated Check	123 a	159 a
Early – Thiamethoxam	4 d	17 d
Recommended – Thiamethoxam	79 bc	106 bc
Late – Thiamethoxam	56 c	85 c
Early – Thiamethoxam/Acephate	-	-
Recommended – Thiamethoxam/Acephate	-	-
Late – Thiamethoxam/Acephate	-	-

[z] Means in the same column followed by the same letter are not significantly different

Table 3. Plant date differences in adult thrips densities at three, four and five weeks after planting in 2013.

	Adult thrips per five plants		
Plant Date	**3 WAP**	**4 WAP**	**5 WAP**
Early	14 c[z]	10 b	22 a
Recommended	24 b	29 a	14 b
Late	32 a	4 b	5 c
LSD[y]	7	8	3

[z] Means in the same column followed by the same letter are not significantly different

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 4. Plant date differences in total thrips densities at three, four and five weeks after planting in 2012 and 2013.

	---------------2012---------------			---------------2013---------------		
Plant Date	**3 WAP**	**4 WAP**	**5 WAP**	**3 WAP**	**4 WAP**	**5 WAP**
Early	-	-	-	18	83 c	64 b
Recommended	29 a[z]	15	12 b	116	131 a	150 a
Late	6 b	10	36 a	122	109 b	26 c
LSD[y]	7	-	11	-	17	25

[z] Means in the same column followed by the same letter are not significantly different

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 5. Plant date differences in immature thrips densities at three, four and five weeks after planting in 2012 and 2013.

	---------------2012---------------			---------------2013---------------		
Plant Date	**3 WAP**	**4 WAP**	**5 WAP**	**3 WAP**	**4 WAP**	**5 WAP**
Early	-	-	-	5	73 b	41 b
Recommended	26 a[z]	13 a	8 b	92	102 a	135 a
Late	5 b	7 b	32 a	90	105 a	22 b
LSD[y]	9	6	10	-	17	26

[z] Means in the same column followed by the same letter are not significantly different

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 6. Insecticide treatment differences of total thrips at three, four, and five weeks after planting in 2012 and 2013.

	---------------2012---------------			---------------2013---------------		
Treatment	**3 WAP**	**4 WAP**	**5 WAP**	**3 WAP**	**4 WAP**	**5 WAP**
Untreated Check	30 a[z]	21 a	32 a	102	143 a	89
Thiamethoxam	14 b	12 b	30 a	69	126 a	78
Thiamethoxam – Acephate	8 b	4 c	11 b	-	55 b	73
LSD[y]	9	7	13	-	24	-

[z] Means in the same column followed by the same letter are not significantly different

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 7. Insecticide treatment differences of immature thrips at three, four, and five weeks after planting in 2012 and 2013.

	--------------2012--------------			--------------2013--------------		
Treatment	**3 WAP**	**4 WAP**	**5 WAP**	**3 WAP**	**4 WAP**	**5 WAP**
Untreated Check	27 a[z]	18 a	27 a	78	128 a	78 a
Thiamethoxam	12 b	9 b	25 a	46	112 a	64 ab
Thiamethoxam – Acephate	8 b	3 b	4 b	-	41 b	56 b
LSD[y]	10	7	12	-	22	17

[z] Means in the same column followed by the same letter are not significantly different

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 8. Plant date differences of dry weights at three, four, and five weeks after planting in 2012 and 2013.

	---------------2012---------------			---------------2013---------------		
Plant Date	**3 WAP**	**4 WAP**	**5 WAP**	**3 WAP**	**4 WAP**	**5 WAP**
		-------------------- grams per plant --------------------				
Early	-	-	-	0.076 b	0.156 b	0.262
Recommended	0.408 a[z]	0.648	1.308 a	0.226 a	0.428 a	0.796
Late	0.216 b	0.414	0.940 b	0.218 a	0.358 a	0.684
LSD[y]	0.090	-	0.200	0.026	0.0.072	-

[z] Means in the same column followed by the same letter are not significantly different

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 9. Effects of the interaction between plant date and insecticide treatment on thrips injury rating at three, four, and five weeks after planting in 2012 and 2013.

	---------------2012---------------			---------------2013---------------		
Interaction	**3 WAP**	**4 WAP**	**5 WAP**	**3 WAP**	**4 WAP**	**5 WAP**
Early – Untreated Check	-	-	-	3.0 bc	3.8 b	4.1 a
Recommended – Untreated Check	-	3.7 a[z]	3.4 a	3.7 a	4.2 a	2.6 c
Late – Untreated Check	-	2.9 b	2.9 b	2.9 c	2.9 d	1.8 d
Early – Thiamethoxam	-	-	-	1.9 e	2.9 d	3.7 b
Recommended – Thiamethoxam	-	2.6 c	2.2 c	3.2 b	3.3 c	1.9 d
Late – Thiamethoxam	-	1.5 e	1.5 e	2.6 d	2.8 d	1.3 e
Early – Thiamethoxam/Acephate	-	-	-	-	2.8 d	2.6 c
Recommended – Thiamethoxam/Acephate	-	2.4 d	1.7 d	-	2.6 e	1.3 e
Late – Thiamethoxam/Acephate	-	1.6 e	1.5 e	-	1.9 f	1.1 f

[z] Means in the same column followed by the same letter are not significantly different.

Table 10. Plant date differences of plant height and number of true leaves at three, four, and five weeks after planting in 2012.

	Plant Height			Number of True Leaves per Plant		
Planting Date	**3 WAP**	**4 WAP**	**5 WAP**	**3 WAP**	**4 WAP**	**5 WAP**
	---------------cm---------------					
Recommended	-	12.8 a[z]	17.7 a	-	4.7 a	6.3 a
Late	-	10.4 b	16.9 b	-	2.9 b	5.9 b
LSD[y]	NS	0.3	0.4	NS	0.2	0.1

[z] Means in the same column followed by the same letter are not significantly different

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 11. Insecticide treatment differences of plant height and number of true leaves at three, four, and five weeks after planting in 2012.

	Plant Height			Number of True Leaves per Plant		
Planting Date	**3 WAP**	**4 WAP**	**5 WAP**	**3 WAP**	**4 WAP**	**5 WAP**
	---------------cm---------------					
Untreated Check	7.3	10.8 b[z]	15.7 b	1.4	3.7 b	6.2 a
Thiamethoxam	7.6	12.1 a	18.0 a	1.6	4.0 a	6.1 ab
Thiamethoxam – Acephate	7.3	12.0 a	18.3 a	1.6	3.9 ab	6.0 b
LSD[y]	NS	0.4	0.5	NS	0.2	0.1

[z] Means in the same column followed by the same letter are not significantly different

[y]LSD – Value of least significant difference according to Fishers Protected LSD at $P \leq 0.05$

Table 12. Effects of the interaction between plant date and insecticide treatment on plant height and number of true leaves at three, four, and five weeks after planting in 2013.

	Plant Height			Number of True Leaves per Plant		
Interaction	3 WAP	4 WAP	5 WAP	3 WAP	4 WAP	5 WAP
	--------------- cm ---------------					
Early – Untreated Check	3.7 f[z]	4.5 f	5.9 h	1.3 d	2.0 f	4.0
Recommended – Untreated Check	6.2 d	7.6 d	10.6 e	1.5 c	4.6 b	6.6
Late – Untreated Check	6.8 c	8.8 c	13.3 d	1.8 b	2.8 e	6.1
Early – Thiamethoxam	5.1 e	5.9 e	7.7 g	1.9 b	2.0 f	3.7
Recommended – Thiamethoxam	7.5 a	9.5 b	14.6 c	2.1 a	4.8 b	7.0
Late – Thiamethoxam	7.2 b	9.8 ab	13.5 d	1.8 b	3.3 d	6.1
Early – Thiamethoxam/Acephate	-	5.7 e	8.6 f	-	2.0 f	4.1
Recommended – Thiamethoxam/Acephate	-	10.1 a	16.4 a	-	5.2 a	7.3
Late – Thiamethoxam/Acephate	-	10.2 a	15.3 b	-	3.7 c	6.3

[z] Means in the same column followed by the same letter are not significantly different

Table 13. Effects of the interaction between plant date and insecticide treatment on lint yield in 2013.

Interaction	------------------------------ Yield ------------------------------ kg lint ha^{-1}
Early – Untreated Check	921 e[z]
Recommended – Untreated Check	1150 c
Late – Untreated Check	890 e
Early – Thiamethoxam	1317 b
Recommended – Thiamethoxam	1406 a
Late – Thiamethoxam	971 de
Early – Thiamethoxam/Acephate	1381 ab
Recommended – Thiamethoxam/Acephate	1370 ab
Late – Thiamethoxam/Acephate	1024 d

[z] Means in the same column followed by the same letter are not significantly different

Table 14. Precipitation (cm) per month from April to October in 2012 and 2013 at Rocky Mount, NC.[z]

Month	2012	2013
	---cm---	
April	8.26	6.83
May	17.73	7.29
June	5.69	25.30
July	17.93	12.52
August	20.60	11.51
September	8.94	12.29
October	6.30	8.26
Total	**85.34**	**84.00**

[z] CRONOS database - State climate office of North Carolina. 2013. Retrieved 12 December 2013 from http://www.nc-climate.ncsu.edu/cronos.