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Impact and Management of Twospotted Spider Mite in Pre-Flowering Cotton

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IMPACT AND MANAGEMENT OF TWOSPOTTED SPIDER MITE IN PRE-

FLOWERING COTTON

By

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Experiments were conducted to determine the impact of twospotted spider mite, *Tetranychus urticae* Koch, on cotton injury and yield. Artificial infestations were initiated at the three leaf stage of cotton growth and removed after specified durations of infestation. Yields were reduced for durations of infestation 21 days or greater. In a second experiment, the interactions between twospotted spider mite, thrips, at-planting insecticides, and foliar insecticides were studied to determine their impact on cotton yields. Twospotted spider mites and thrips reduced cotton yield. In a third experiment, twospotted spider mites were released from a central point in 0.024 hectare blocks of cotton and injury was recorded at various distances from that point. Injury was clearly visible seven meters from the infestation point within 16-28 days after infestation. Twospotted spider mites caused significant yield losses in cotton in all of these experiments.

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CHAPTER I

LITERATURE REVIEW

Introduction

Twospotted spider mite, *Tetranychus urticae* Koch, is a major pest of many horticultural and agricultural crops worldwide (Kavousi et al. 2009). *Tetranychus urticae* has more than 900 recorded species of host plants (Kavousi et al. 2009). It was the third most damaging arthropod pest of cotton, *Gossypum hirsutum* L., during 2009 in Mississippi, with a total of 6,627 bales lost (Williams 2010). Typically, twospotted spider mite infestations in cotton occur in the latter part of the growing season for Mississippi. However, early season spider mite infestations have become more prevalent in some cotton fields since 2005 (A. L. Catchot, personal communication)

Twospotted spider mite is taxonomically classified in the class Arachnida, subclass Acari, order Trombidiformes, suborder Prostigmata, and family Tetranychidae (Jeppson et al. 1975). Early Greek scientists classified various mite species in Acari in Egypt as early as 1550 B.C. (Jeppson et al. 1975).

Mites within the subfamilies Tetranchoidae and Eriophuoidea comprise most of the plant feeding species (Jeppson et al. 1975). Mites can be distinguished from other arachnids, such as spiders, due to their lack of abdominal segments. The most defining characteristic of the class Arachnida is the chelicerate mouthparts and lack of antennae (Jeppson et al. 1975). Tetranychids possess long needle-like chelicerae and palpal thumb claws which differ from other mite species that have forceps-like chelicerae (Jeppson et al. 1975).

The life cycle of the twospotted spider mite consists of egg, larva, protonymph, deutonymph, and adult (Cagle 1949). To complete each nymphal instar, twospotted mites anchor themselves and molt to the succeeding stage (Boudreaux 1963). Twospotted spider mites complete their entire life cycle in 7-12 days at 29°C (Boudreaux 1963). However, development times can vary greatly depending on temperature.

The eggs are spherical and translucent in appearance. They are approximately 0.1 mm in diameter (Jeppson et al. 1975). Eggs are laid within silk webbing that is typically bound to the underside of the leaves (Jeppson et al. 1975). The silk webbing serves two main functions. It is hydrophilic, regulating the micro-environment around the egg and serves as a territorial marker by the female (Hazan et al. 1974). It is hypothesized that the hydrophilic nature of the webbing serves as a humidity regulation mechanism during hot dry ambient conditions (Hazan et al. 1974). After emergence, both male and female twospotted spider mites pass through three immature stages.

The three immature stages of twospotted spider mites include the larva, protonymph, and deutonymph (Shih et al. 1976). Nymphs can be pale yellow, green, or transparent in color and varies depending upon host plant. Nymphs in the protonymph and deutonymph stages will express the characteristic greenish or black spots on the abdomen (Potter et al. 1976). These lateral spots alongside the abdomen are collections of waste build-up that are seen through the translucent body wall (Potter et al. 1976). The larval stage of *T. urticae* has 6 legs; whereas, the protonymph and deutonymph stages have 8 legs (Jeppson et al. 1975). Shih et al. (1976) found that larvae were less active compared to protonymphs and deutonymphs. Larvae were observed as non-feeding and protonymphs feed less than deutonymphs (Shih et al. 1976). The duration of each nymphal stage is temperature dependant. After the deutonymph stage, spider mites will enter a quiescent period prior to adulthood.

The adult female twospotted spider mite is approximately 0.65 mm long and oval in shape. The adult male is slightly smaller than the female (Jeppson et al. 1975). Both the adult male and female are pale yellow or greenish in color with two lateral dark green or black spots on their abdomen. Potter et al. (1976) observed male twospotted spider mites completing adult development earlier than female mites. Adult males will actively search out and follow a female deutonymph until she reaches adulthood (Potter et al. 1976). Males are guided to these females by pheromones released during ecdysis (Potter et al. 1976). This behavior is known as 'guarding' (Potter et al. 1976). Male twospotted spider mites will exhibit aggressive behavior toward other approaching males during the guarding behavior (Potter et al. 1976). Adult females will begin mating soon after they molt to the adult stage. Mate selection is based on the male that is first to arrive (Potter et al. 1976). After eggs are fertilized, female twospotted spider mites will attach webbing near the veins on the underside of the leaves for oviposition. Potter et al. (1976) describes twospotted spider mite as an arrhenotokous species. Mated females can produce male or female offspring and unmated females can only produce male offspring.

The biology, polyphagous habit, and over-lapping generations of twospotted spider mite can be associated with their ability to be a pest of cotton and other crops. Cotton losses due to twospotted spider mite are strongly influenced by environmental conditions and at what plant growth stage infestations occur (Reddall et al. 2004). Significant reductions in cotton yield, fiber quality, and seed viability in cotton are all related to when twospotted spider mite infestations occur and the rates of population development (Wilson 1993a). Furr and Pfrimmer (1968) observed a significant decrease in cotton yields when plants were infested early-season and mid-season, but did not observe yield reductions in late season infested cotton.

Twospotted spider mite feeding injury is characteristic of most polyphagous spider mites. Twospotted spider mites are capable of feeding on any portion of the leaf but prefer feeding on the abaxial surface (Reddall et al. 2004). Twospotted spider mites use their stylets to pierce plant cells and digest the cellular contents (Riley 1989). The chloroplast within the cells is removed leaving dead cells which eventually turn yellowish to brown and red in color (Riley 1989). Thus, twospotted spider mite feeding results in an overall reduction in photosynthesis and desiccation of cotton leaves (Reddall et al. 2004).

Twospotted spider mites can have multiple overlapping generations in a relatively short period of time. This allows twospotted spider mites to reach damaging densities quickly. Damage intensity can be classified as light damage when leaves exhibit pale yellow mottling, and heavy damage when leaves show red-brown discoloration (Reddall et al. 2004). These two measurements correspond with other commonly used identification methods to quantify spider mite densities and injury.

Arthropod Pests

The early season pest complex of cotton is comprised of multiple arthropods. Thrips and twospotted spider mite are the most important arthropod pests of cotton seedlings in the mid-South. Tobacco thrips, *Frankliniella fusca* (Hinds), is the dominate thrips species found on cotton seedlings in the mid-South (Cook et al. 2003). Cook et al. (2003) found four major thrips species in Mississippi cotton fields. They included tobacco thrips; flower thrips, *Frankliniela tritici* (Fitch); soybean thrips, *Neohydatothrips* *variabilis* (Beach); and onion thrips, *Thrips tabaci* Lindeman. Of these four thrips species, tobacco thrips were more abundant than any other species (Burris et al. 1990, Cook et al. 2003).

Thrips damage cotton seedlings by rupturing epidermal cells and extracting the cellular contents as a food source (Cook et al. 2011). This type of feeding creates malformed stunted cotton leaves that can tear as they expand (Cook et al. 2011). Monitoring for thrips can be done by inspecting the whole plant in the field or a more precise count of thrips densities can be achieved using a whole plant washing technique (Burris et al. 1990).

Systemic and contact insecticides are available for thrips control. These include in-furrow insecticides such as aldicarb (Temik 15G, Bayer CropScience, Research Triangle Park, NC), foliar sprays with broad spectrum insecticides, or seed treatments such as imidacloprid (Gaucho Grande 5 FS, Bayer CropScience, Research Triangle Park, NC) and thiamethoxam (Cruiser 5FS, Syngenta Crop Protection, Greensboro, NC) (Cook et al. 2011). Burris et al. (1990) examined the population dynamics of various thrips and aphid species in the presence of foliar applied acephate (Orthene 90WSP, Amvac Chemical Corporation, Walnut Creek, CA) and aldicarb applied in-furrow. Both insecticides reduced overall pest populations when compared to the control. Aldicarb is a systemic carbamate acetyl cholinesterase inhibitor that is translocated systemically and expressed throughout plant tissue (Lohmeyer et al. 2003). Imidacloprid plus thiodicarb (Aeris 5FS, Bayer Crop Science, Research Triangle Park, NC) is a neonicotinoid, acetyl choline receptor agonist, and a carbamate, acetylcholinesterase inhibitor, that are applied to seed and systemically translocated throughout all plant parts after emergence. Acephate can be applied foliar, seed t applied acetylcholinesterase inhibitor.

Population Dynamics

Twospotted spider mite populations are affected by numerous biotic and abiotic factors such as environmental conditions, chemical applications, pathogens, predators, and parasitoids. Management with some insecticides, such as bifenthrin, may provide temporary suppression of spider mites. Insecticides may also inadvertently cause an increase in spider mite populations by removing beneficial insects and mites that would suppress spider mites populations through predation (Jeppson et al. 1975). Because of this, acaricides are recommended for spider mite control in most situations.

Environmental conditions directly affect spider mite population dynamics. Temperatures greater that 33°C will result in increasing reproductive rates and decreasing generation time (Klubertanz et al. 1991). At 27 °C, twospotted spider mites are able to develop from egg to adult in 5.6 days (Shih et al. 1976). Dry environmental conditions will promote spider mite metabolic rates by increasing their demand for nutritional fluids (Boudreaux 1958). Rainfall can decrease spider mite populations by reducing the ambient temperatures which decreases spider mite fecundity and increases the incidence of pathogens (Klubertanz et al. 1990). Jeppson et al. (1985) found that spider mites take shelter within the webbing on the abaxial surface of leaves to avoid rainfall. Studies have shown that spider mite population densities are higher in seasons of drought and high ambient temperatures than cooler and wetter seasons.

Management

Monitoring twospotted spider mite populations can be laborious and time consuming (Wilson et al. 1983). Because of this, sampling is often based on a presence or absence binomial method. Action thresholds for Mississippi are based upon plant infestation or damage levels of 40-50% when environmental conditions are favorable for sustainable population increases (Catchot 2011).

Twospotted spider mite populations can be reduced with the use of miticides that have either contact or translaminar activity. Miticides with contact activity include bifenthrin, dicofol, fenpyroximate, and propargite. Miticides with translaminar activity include abamectin, etoxazole, and spiromesifen.

In some situations, natural enemies can regulate spider mite populations through predation of eggs, immatures and adults. Various natural enemies such as, big eyed bug *Geocoris pallens* Stal and *G. punctipes* Say; minute pirate bug, *Orius tristicolor* (White); western flower thrips, *Frankliniella occidentalis* (Pergande); and mites in the family Phytoseiidae, are omnivorous predators of spider mites in cotton (Smith and Furr 1975). These natural enemies feed on spider mite eggs, larvae, nymphs, and adults which reduce population densities. However, they are generalist predators and provide little suppression of robust spider mite infestations.

Fungal pathogens such as *Neozygites floridana* Weiser and Muma, can effectively reduce spider mite populations during times of epizootics (Brandenburg and Kennedy 1982b). Optimal fungal activity of *N. floridana* is at 100% ambient relative humidity and temperatures between 15-26°C. Jeppson et al. (1975) also found *N. tetranychi* Weiser; can reduce various spider mite populations when humidity is high.

Miticides and insecticides have been extensively studied for their effectiveness against twospotted spider mites. Control of twospotted spider mites with contact miticides can sometimes prove to be difficult given their placement on the leaf. Because of that, miticides with translaminar activity usually provide the most consistent levels of control under a wide range of situations.

Leigh (1963) showed that side dressing organophosphates like phorate (Thimet 20G, AMVAC) and dimethoate (Dimethoate 4EC, Helena Chemical Company, Collierville, TN) will provide acceptable control of mite populations in cotton (Leigh 1963). Ridgway and Garzycki (1965) found that phorate, aldicarb, and dimethoate provided the greatest control of carmine spider mites, *Tetranychus cinnabarinus* Boisduval, when applied in furrow at planting (Ridgway et al. 1965). Granular formulations of aldicarb, applied in the seed furrow reduced spider mite populations better than phorate or disulfoton (Hagel 1970). Imidacloprid is a common seed applied insecticide used at planting to control early season pests in cotton. As stated previously, imidacloprid provides satisfactory thrips control when applied as a seed treatment on cotton. However, it is thought to increase spider mite populations due to natural enemy suppression. Sclar et al. (1998) found that imidacloprid increased spider mite populations and injury on two different host plants and with two different tetranychid mite species.

Spatial Distribution

Twospotted spider mites are referred to as colony forming mites. Colony forming mites tend to move less and aggregate with increased rates of reproduction (Slone and Croft 1998). Crawling and wind dispersal serve as the two main mechanisms of spider mite dispersal (Wilson et al. 1983). Crawling serves as the dispersal mechanism for twospotted spider mites early in the season when they move from border vegetation into neighboring corn fields (Brandenburg and Kennedy 1982a). Wind serves as their dispersal mechanism during the latter part of the season when formerly suitable hosts such as corn begin to senesce (Wilson et al. 1983).

Multiple factors contribute to twospotted spider mite dispersal such as fecundity, development, territoriality, mate searching, and response to plant quality (Slone and Croft 1998). Spider mites are negatively geotactic, meaning as the season progresses, they move up the plant to feed and reproduce (Hussey and Parr 1963). Their ability to move up the plant as the season progresses may contribute to their ability to aggregate and disperse by wind or phoresy (Slone and Croft 1998). Wilson et al. (1983) found this aggregated pattern to change into random dispersal as competition and crowding increased.

Precision Agriculture

Precision agriculture is a concept that integrates spatial technologies and principles to manage spatial and temporal variability in crop vigor to improve overall crop performance (Pierce and Nowak 1999). Precision agriculture has prospered due to foundational concepts of Global Positioning Systems (GPS), geographic information systems (GIS), and in-field remote sensing (Zhang et al. 2002). Understanding, developing, and implementing precision practices can prove laborious and expensive. Thus, the overall adoption of precision agriculture technologies by farmers has been erratic (Zhang et al. 2002). Precision agriculture allows for an evaluation of crops and pests over time and space. With precision agriculture, spatial and temporal variability in field characteristics, soil dynamics, and crop vigor can be quantified (Zhang et al. 2002). Little research has been done to develop pest management models using precision agriculture technologies that quantify spatial and temporal variability of arthropod populations.

Remote sensing is a precision technology tool that acquires information about an object without being in direct contact with the object (Riley 1989). Aerial sensors and cameras can be used to capture the near infrared light reflectance of large areas of vegetation (Riley 1989). Vegetation indices can then be developed using the data collected and combining or contrasting it to other spectral wavelengths (Riley 1989). Remote sensing has a broad spectrum of uses in agriculture, including entomology. There are three areas of application where remote sensing can be utilized in row crop entomology: monitoring of environmental factors that influence insect behavior, direct observation of insects, and the detection of the effects that insects produce on the crop (Riley 1989).

Detecting the effects that insects produce on crops can play a vital role in connecting precision pest management with integrated pest management. Foley et al (1998) showed that water absorbs large amounts of near infrared radiation. Healthy plants will absorb light energy in the near infrared wavelengths (Mahey et al. 1991, Foley et al. 1998). Mahey et al. (1991) showed that irrigated crops have a higher normalized vegetation difference index than non-irrigated crops (Mahey et al. 1991). Due to the damage caused by spider mites in cotton, near infrared light energy and normalized vegetation indices can be acquired and may identify spider mite “hot spots” in cotton fields using this technology (Reisig and Godfrey 2006).

This research project was undertaken to develop an understanding of the impact twospotted spider mites have on cotton in the mid-South. Twospotted spider mites are considered a pest of cotton seedlings in the mid-South. However, little is known about their effects on cotton yields during this growth period. More so, spider mites movement from winter annuals onto neighboring crops in early spring is well documented, but their temporal and spatial dispersal and injury rate on cotton are unclear. The goal of this thesis is to address the impact of early season twospotted spider mite infestations on cotton production.

CHAPTER II

IMPACT OF TWOSPOTTED SPIDER MITE DURATION OF INFESTATION ON COTTON SEEDLINGS

Abstract

The yield response of cotton, *Gossypium hirsutum* L., to twospotted spider mite, *Tetranychus urticae* Koch, duration of infestation during the seedling stage was measured at Starkville and Stoneville, MS during 2010 and 2011. The treatments included an un-infested control, infestations lasting for 7, 14, 21 or 28 days, and a season long infested control. Twospotted spider mites from a greenhouse colony were inoculated on all of the infested cotton plots during the 3-leaf stage. Applications of miticides were made to terminate infestations at the desired timings for each treatment. Twospotted spider mite densities and injury ratings were determined for each treatment at the end of the infestation period and yield was measured at the end of the season. Twospotted spider mite densities and injury rating significantly increased as duration of infestation increased. Significant differences in yield were observed between treatments. Twospotted spider mite infestations that persisted longer than 14 days significantly reduced cotton yield compared to the un-infested control. Based on these data, spider mite densities on cotton seedlings should not be allowed to persist longer than 14 days before management is initiated.

Introduction

Twospotted spider mite, *Tetranychus urticae* Koch, is a major pest of many horticultural and agricultural crops (Kavousi et al. 2009). It has more than 900 recorded species of host plants around the world (Kavousi et al. 2009). Twospotted spider mite was the third most damaging arthropod pest of cotton during 2009 in Mississippi, with a total of 6,627 bales lost (Williams 2010). Typically, infestations in cotton occur during the latter part of the growing season in Mississippi. However, early season twospotted spider mite infestations have become more prevalent in some cotton fields since 2005 (A. L. Catchot, personal communication).

Twospotted spider mite prefers feeding on the abaxial surface of leaves (Reddall et al. 2004). Their feeding injury is characteristic of most polyphagous spider mites. Spider mites use stylets to pierce plant cells and digest the cellular contents (Riley 1989). The chloroplast within the cells is removed, leaving dead cells which eventually turn yellowish to brown and red in color (Riley 1989). This type of feeding leaves a characteristic stippling and reddening appearance to cotton. Feeding injury results in an overall reduction in photosynthesis and desiccation of cotton leaves (Reddall et al. 2004). Damage may only be easily distinguishable in late season cotton when canopy closure has occurred.

Cotton losses due to spider mites are strongly influenced by seasonal conditions and the timing of infestations (Reddall et al. 2004). Damage intensity can be classified as light damage when leaves exhibit pale yellow mottling and heavy damage when leaves show red-brown discoloration (Reddall et al. 2004). These two measurements correspond with other commonly used identification methods of twospotted spider mite injury. Significant reductions in cotton yield, fiber quality, and seed viability in cotton are all related to when twospotted spider mite infestations occur and rate of population development (Wilson 1993a). Furr and Pfrimmer (1968) showed significant decreases in cotton yields when plants were infested during early and mid-season. Yield reductions were not observed for late-season infestations in cotton (Furr and Pfrimmer 1968). Previous research in Australia found early infestations (at early flowering) of twospotted spider mites affected overall boll set and size (Wilson 1993b).

Twospotted spider mite biology, polyphagous habits, short generation times, and over-lapping generations contribute to their pest status in cotton and other crops. At 27°C, twospotted spider mites are able to develop from egg to adult in 5.6 days (Shih et al. 1976). This allows twospotted spider mites to reach damaging densities in a relatively short period of time. Further research is needed to determine how long early season infestations can persist before significant yield losses are observed in cotton. The objective of this experiment was to investigate the impact of durations of twospotted spider mite infestations on yield in early season cotton.

Materials and Methods

Experiments were conducted during 2010 and 2011 to investigate the impact of twospotted spider mite infestation duration on cotton seedlings at the R. R. Foil Plant Science Research Center located in Starkville, MS and at the Delta Research and Extension Center in Stoneville, MS.

Deltapine 1034 B2RF and Stoneville 4498 B2RF were the varieties planted in Starkville and Stoneville, respectively, during 2010. Phytogen 499 WRF and Phytogen 375 WRF were the varieties planted in Starkville and Stoneville, respectively, during 2011. Plant populations ranged between 98,800 to 111,150 plants per hectare for all locations during both years. During 2010 at Starkville, MS, all plots were planted on May 14, 2010; infested on June 4, 2010; and rated on June 11, 18, 25, and July 1, 2010. At Stoneville, MS in 2010, all plots were planted on June 6, 2010; infested on June 18, 2010; and rated on June 25, July 2, 9, and 16, 2010. At Starkville, MS in 2011, all plots were planted on June 01, 2011; infested on June 27, 2011; and rated on July 4, 12, and 19, 2011. At Stoneville, MS in 2011, all plots were planted on May 16, 2011; infested on June 7, 2011; and rated on June 14, 21, 28, and July 5, 2011.

Treatments were arranged in a randomized complete block design with four replications. Each plot consisted of four rows on 1.02 m centers that were 6.09 meters in length. Two rows of unplanted bare soil were left between each plot to reduce twospotted spider mite migration between plots. Replications were separated with 3.04 meters of unplanted bare soil to reduce twospotted spider mite migration between replications. Treatments consisted of an un-infested control, infested at the third leaf growth stage and removed after a fixed duration of 7, 14, 21, or 28 days after infestation, and an infested control that was infested at the third leaf stage and remained infested until physiological maturity.

All plots, except the un-infested control, were infested when plants across the test area averaged the three leaf stage. Only the center two rows of each plot were infested. The source of twospotted spider mites came from a greenhouse colony located on the Mississippi State University campus and reared on Kentucky Wonder bush green beans, *Phaseolus vulgaris* L. Twospotted spider mite populations ranged between 150-300 mites per bean plant per row foot. The infested green beans were clipped near the soil surface and placed directly over the top of cotton plants, ensuring direct contact between cotton foliage and green bean foliage.

Sampling consisted of twospotted spider mite population density estimates and injury ratings. Plots within each treatment were sampled at the end of the respective infestation period 7, 14, 21, or 28 days after infestation prior to mites being removed with a miticide application. Twospotted spider mite densities within each plot were determined using a 6.45 cm^2 lens with 10X magnification. Five samples (32.25 cm^2) were taken within each plot. The primary leaf at the third node from the terminal was sampled. Twospotted spider mites were recorded from the base of the abaxial side of the leaf. Degree of twospotted spider mite injury was determined using a 0-5 scale of reddening and stippling of leaves where; 0 = no damage, 1 = light stippling occurring on the leaf, 2 = stippling and reddening occurring on 15-20% of the leaf, 3 = 20-50% of the leaf has definite reddening on basal portions, 4 = greater than 50% of the leaf contains extensive reddening, 5 = greater than 75% of the leaf shows extensive reddening (Smith 2010). All injury ratings were determined using the primary leaf at the third node from the terminal at each rating date.

When plots reached the specified duration of twospotted spider mite infestation they were treated with a miticide to eliminate existing twospotted spider mite populations. Abamectin (Agri-Mek 0.15 EC, Syngenta Crop Protection, Greensboro, NC) was applied at a rate of 0.0131 kg ai/ha on a weekly basis after initial removal of twospotted spider mites to ensure re-infestation did not occur. Yields were obtained using a 2-row John Deere spindle type cotton picker to harvest the center two rows. Each plot weight was recorded in kilograms seed cotton per hectare. Lint weight was calculated assuming 38 percent lint turnout. Rainfall data were collected for the infestation periods from a weather station at each respective location.

All data were analyzed with a mixed model analysis of variance (PROC MIXED, SAS Institute, Version 9.2). For twospotted spider mite injury ratings and densities, the ratings for the un-infested control were all 0, so it was not included in the final analysis. The infested control had mite injury ratings similar to the 28 day rating, so it was not included in the final analysis. For analysis of injury ratings, mite densities, and yield, duration of infestation was designated as a fixed effect in the model. Replication nested within test year (location) was designated as a random effect in the model. For all analyses, degrees of freedom were calculated using the Kenwood-Rodgers method. Means were calculated using the LSMEANS statement and separated based on Fisher's protected least significant difference ($\alpha = 0.05$).

Results and Discussion

Cumulative precipitation for Starkville, MS was 4.73 cm between June 4, 2010 and July 01, 2010 (Figure 2.1). Cumulative precipitation for Stoneville, MS was 1.57 cm between June 18, 2010 and August 16, 2010 (Figure 2.2). During 2011, precipitation was sparse at both locations and no effect was seen with twospotted spider mite population densities across all rating dates (Figures 2.3 and 2.4). A single rainfall event is less likely to inhibit twospotted spider mite injury but continuous rainfall events throughout the growing season could negatively affect their feeding habits, mobility, and population survivorship even at low levels of precipitation (Klubertanz et al. 1990). The treatment by year interaction was not significant ($F=1.18$, $df=5, 83$, $P=0.33$). Therefore, all locations and years were combined for the final analyses.

Duration of infestation had a significant effect on twospotted spider mite population densities when averaged across locations and years ($F=5.13$, $df=3, 52$, *P*=0.04) (Figure 2.5). As duration of infestation increased, twospotted spider mite populations increased. Significantly more twospotted spider mites were observed at infestation durations of 21 days and 28 days compared to 7 days. Additionally, more twospotted spider mites were observed at 28 days than at 14 days. Average twospotted spider mite densities ranged from approximately 8.5, 12.7, 15.2, and 20.8 per 32.26 cm^2 at 7, 14, 21, and 28 days after infestation, respectively. Furr and Pfimmer (1968) observed similar twospotted spider mite densities that resulted in a reduction in cotton yield of 31 percent and 35 percent in plots artificially infested early (at squaring) and mid-season (at first bloom).

Duration of infestation also had a significant effect on injury ratings averaged across locations and years (F=40.33, df =3, 52, *P*<0.01) (Figure 2.6). Significant injury was observed across all treatments. Mean injury ratings occurring at 14, 21, and 28 days after infestation were significantly higher than mean injury ratings at 7 days after infestation. Additionally, injury ratings at 21 and 28 days after infestation were significantly higher than mean injury ratings at 14 days after infestation. Mean injury ratings ranged from less than 1 at 7 days after infestation to over 3 at 28 days after infestation.

Duration of infestation had a significant effect on cotton yields when averaged across locations and years (F=7.25, df=5, 86, *P*<0.01) (Figure 2.7). Yields were significantly reduced in the 21 day duration of infestation, 28 day duration of infestation, and infested control treatments when compared to the un-infested control and the 7 day duration of infestation. Furr and Pfrimmer (1969) observed significant yield reductions in plots artificially infested with twospotted spider mites early (infested at squaring) and mid-season (infested after first bloom) when compared to late season infestations.

Currently, Mississippi action threshold for twospotted spider mite control in cotton is when 40-50 percent of plants are infested and environmental conditions are conducive for populations to increase (Catchot 2011).

Twospotted spider mites can be suppressed by natural enemies, predatory mites, rainfall, or fungi (Leigh et al. 1967, Oatman 1970, Klubertanz et al. 1990, 1991). However miticides provide optimal control of twospotted spider mite populations in cotton (Furr and Davis 1969). These data suggest infestations initiated at the three leaf cotton growth stage with population densities at a minimum of 12.7 per 32.26 cm^2 existing greater than 14 days should be treated with a miticide to avoid reduction of cotton yields.

These results may vary significantly under different environmental conditions. Further experiments using artificial infestation techniques similar to those used in these experiments should be done to investigate the yield loss potentially occurring at various growth stages for extended periods of time in cotton. Information from this experiment will be important for developing accurate thresholds in cotton seedlings.

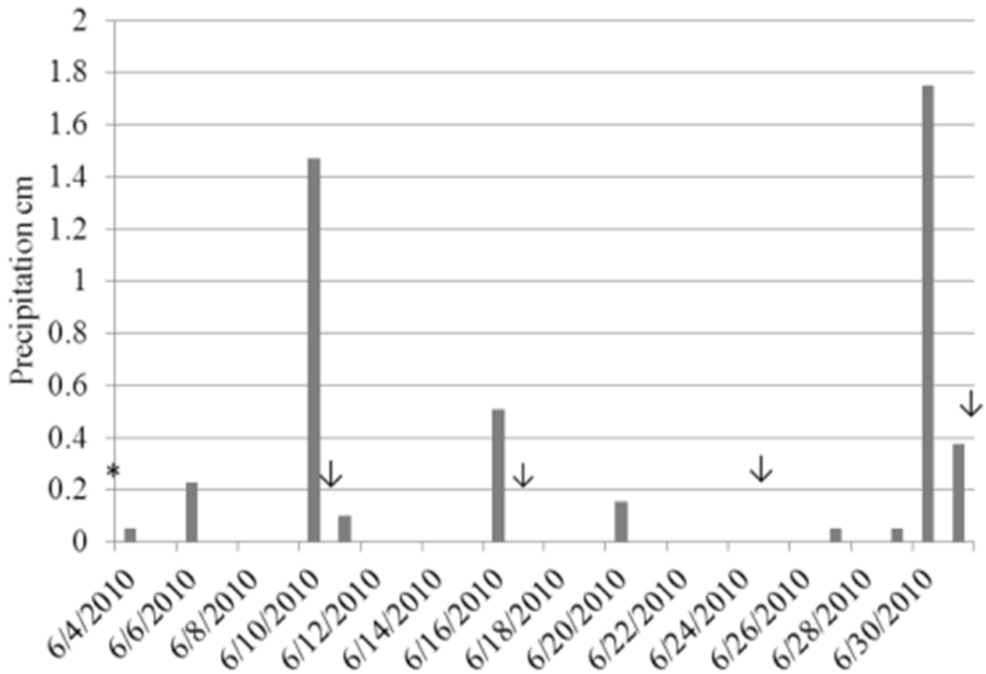

Figure 2.1 Precipitation from the time of infestation until the last rating date during 2010 at Starkville, MS. (*Denotes when plots were infested. ↓ Denotes when plots were rated for thrips and twospotted spider mite densities).

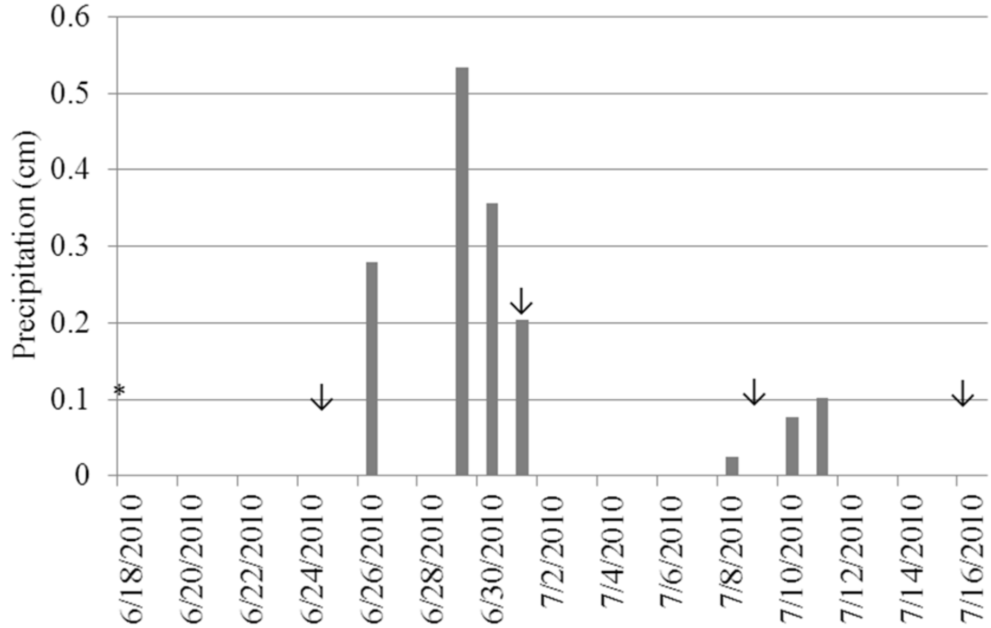

Figure 2.2 Precipitation from the time of infestation until the last rating date during 2010 at Stoneville, MS. (*****Denotes when plots were infested. ↓ Denotes when plots were rated for thrips and twospotted spider mite densities).

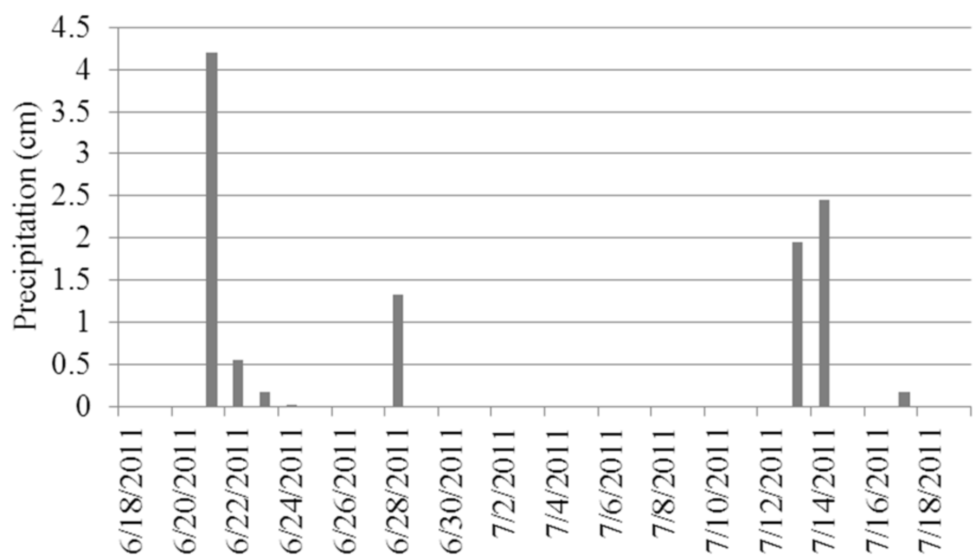

Figure 2.3 Precipitation from the time of infestation until the last rating date during 2011 at Starkville, MS.

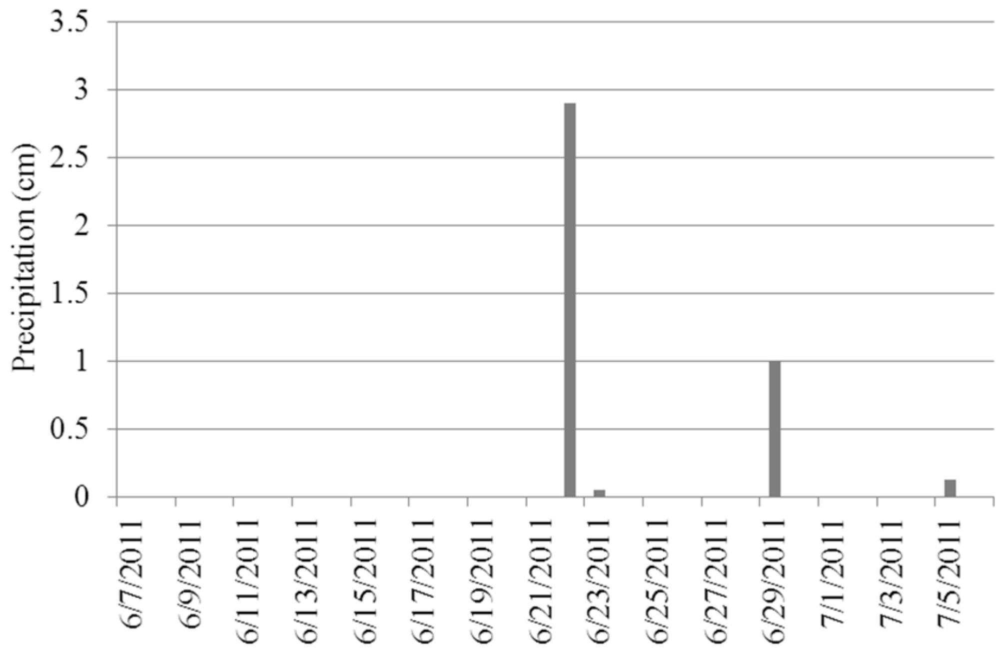

Figure 2.4 Precipitation from the time of infestation until the last rating date during 2011 at Stoneville, MS.

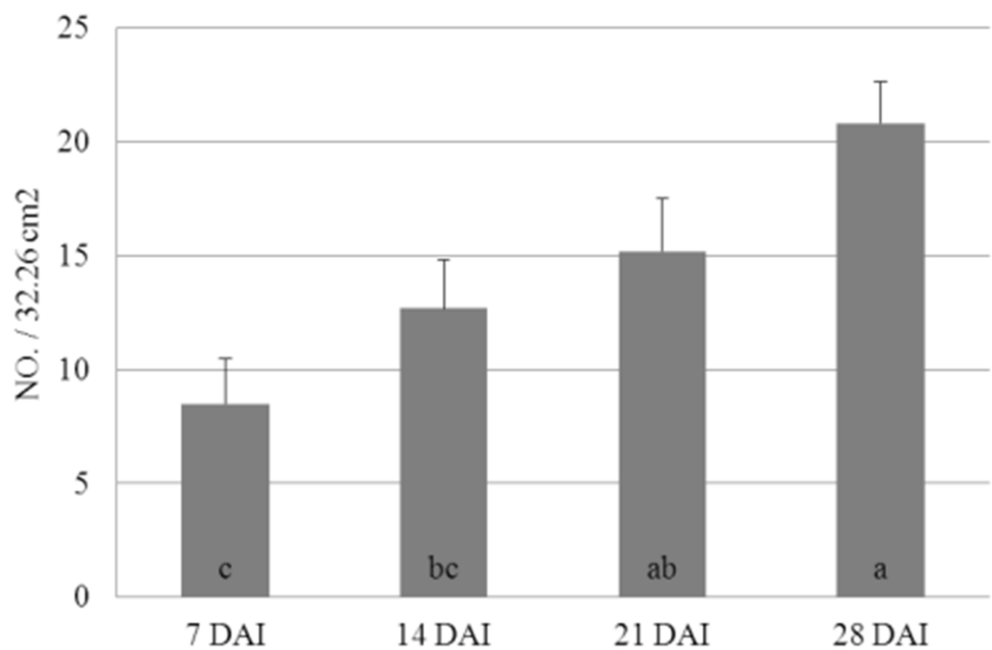

Figure 2.5 Mean (SE) twospotted spider mite densities averaged across both locations and years. Means followed by a common letter are not significantly different (α=0.05). DAI denotes days after infestation.

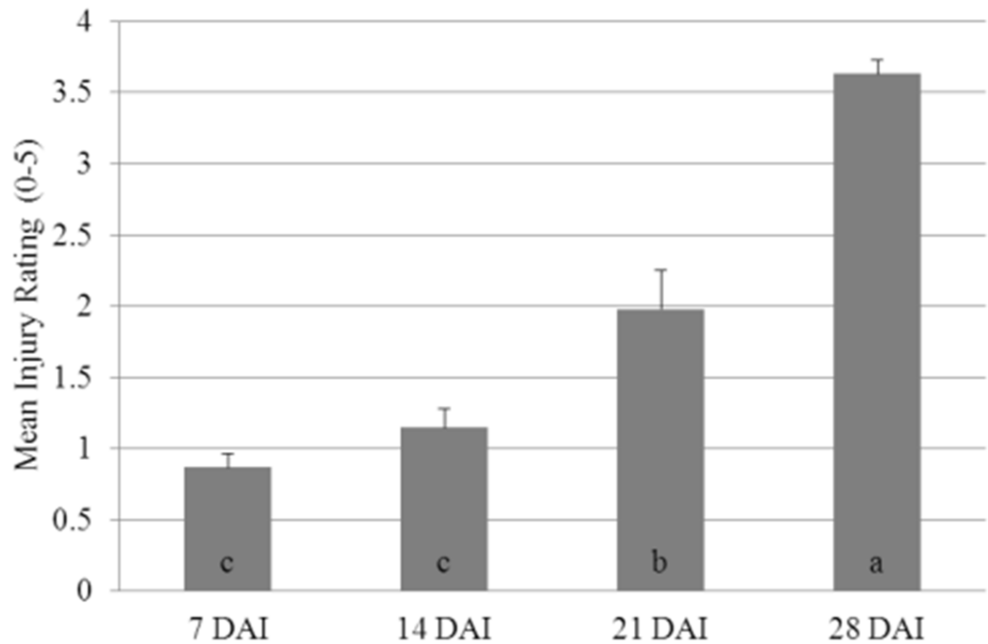

Figure 2.6 Mean (SEM) twospotted spider mite injury ratings averaged across both locations and years. Means followed by a common letter are not significantly different (α=0.05). DAI denotes days after infestation.

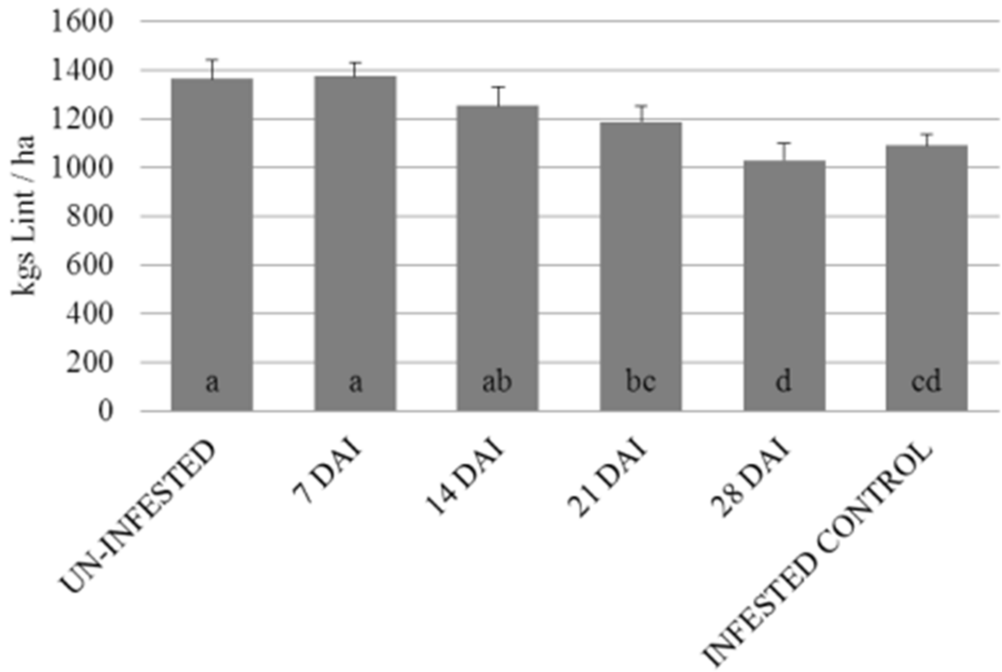

Figure 2.7 Impact of twospotted spider mite durations of infestations on mean (SE) cotton yields averaged across both locations and years. Means followed by a common letter are not significantly different (α=0.05). DAI denotes days after infestation.

CHAPTER III

IMPACT OF TWOSPOTTED SPIDER MITE AND TOBACCO THRIPS IN THE PRESENCE OF INSECTICIDAL SEED TREATMENTS AND FOLIAR ACEPHATE IN COTTON

Abstract

The yield response of cotton, *Gossypium hirsutum* L., to twospotted spider mite, *Tetranychus urticae* Koch, and tobacco thrips, *Frankliniella fusca* Hinds, infestations, imidacloprid plus thiodicarb applied as a seed treatment, aldicarb applied in-furrow at planting, and acephate applied at two specific cotton growth stages was measured at Starkville, MS and Stoneville, MS during 2010 and 2011, respectively. Treatments included three levels of at-planting insecticides, three levels of foliar thrips management, and two levels of twospotted spider mite infestation. Acephate is a common organophosphate insecticide used in the mid-South to control thrips on cotton seedlings. In this experiment, acephate provided good control of thrips 11-14 and 2-7 days after the 1-2 and 3-4 leaf foliar applications, respectively. Imidacloprid plus thiodicarb seed treatment and aldicarb soil applied insecticides provided sufficient thrips control with or without a supplemental acephate application at both the 1-2 and 3-4 leaf growth stage. The 3-4 leaf acephate application was the most beneficial foliar acephate application in terms of yield where an at-planting insecticide was not used. Although there were no significant differences in yield nor did the 1-2 or 3-4 leaf foliar acephate application significantly increase yield in the aldicarb or imidacloprid plus thiodicarb treatments.

These data suggest no significant positive benefit to an additive foliar acephate application to cotton seedlings that had imidacloprid plus thiodicarb seed treatment or aldicarb soil applied insecticides.

Introduction

The early season pest complex in cotton, *Gossypium hirsutum* L., is comprised of multiple arthropods. Of that complex, various species of thrips are the most important in terms of percentage of hectares infested and treated during the first few weeks of plant development. Thrips infest every cotton field in Mississippi at some level annually (Williams 2011). The most common species of thrips found on cotton seedlings in the mid-South is the tobacco thrips, *Frankliniella fusca* (Hinds), (Cook et al. 2011). Other species that have been observed in cotton seedlings in the mid-South include flower thrips, *F. tritici* (Fitch); soybean thrips, *Sericothrips variabilis* (Beach); and onion thrips, *Thrips tabaci* (Lindeman) (Cook et al. 2011). Thrips damage cotton seedlings by rupturing epidermal cells and extracting the cellular contents as a food source (Cook et al. 2011). This type of feeding creates a malformed stunted cotton leaf which can tear as the leaf expands (Cook et al. 2011). Agricultural consultants and pest managers monitor thrips densities in cotton and base insecticide application recommendations on whole plant inspections. More accurate and precise measures of estimating thrips densities in research can be achieved by a whole plant washing technique (Burris et al. 1990).

Nearly every cotton field in the mid-South is treated for thrips annually (Williams 2011). Options for thrips control in cotton include at-planting insecticides and foliar insecticides. Historically, aldicarb (Temik 15G, Bayer CropScience, Research Triangle Park, NC) was the standard for thrips control in cotton seedlings. It is a granular insecticide/nematicide that is applied in-furrow at the time of planting and provides good control of thrips, other arthropod species, and nematodes (Carbide 1975). More recently, insecticidal seed treatments have become the standard for thrips control. Imidacloprid (Gaucho Grande 5FS, Bayer CropScience, Research Triangle Park, NC) and thiamethoxam (Cruiser 5FS, Syngenta Crop Protection, Greensboro, NC) were the first insecticidal seed treatments from the neonicotinoid class in cotton (Cook et al. 2011). Their initial adoption was relatively slow, because they do not have nematicidal activity. As a result, commercial formulations of imidacloprid plus thiodicarb (Aeris 5FS, Bayer CropScience, Research Triangle Park, NC) and thiamethoxam plus abamectin (Avicta Complete Pak, Syngenta Crop Protection, Greensboro, NC) were introduced to control both thrips and nematodes (Cook et al. 2011). The seed treatments provide good control of insect pests from seedling emergence until 3-4 weeks after emergence (Cook et al. 2004).

Foliar application with an organophosphate insecticide is another option for thrips control in cotton. Acephate (Orthene 90S, Amvac Chemical Corp., Walnut Creek, CA), dimethoate (Dimethoate 4 EC, Helena Chemical Co., Collierville, TN), and dicrotophos (Bidrin 8E, Amvac Chemical Corp., Walnut Creek, CA) are the most commonly used foliar insecticides for thrips control in cotton seedlings because they are effective and relatively inexpensive. All of these options (in-furrow, seed treatment, and foliar sprays) are effective for thrips management, but have certain strengths and weaknesses for management of other pests. In particular, aldicarb provides suppression of spider mites (Acari: Tetranychidae); while the insecticidal seed treatments are thought to be fairly innocuous and foliar sprays can disrupt natural enemy populations and release spider mites.

Twospotted spider mite has become a more important early season pest of cotton in recent years. The shift from aldicarb to neonicotinoid seed treatments is thought to be partially responsible for the increase in early season twospotted spider mite infestations in cotton. Several factors may have contributed to this. Aldicarb provides some control of twospotted spider mites during the seedling stages of cotton (Ridgway and Garzycki 1965, Hagel 1970); whereas imidacloprid and thiamethoxam do not. Additionally, supplemental foliar applications are often needed to control thrips on cotton seedlings where a seed treatment was used. These applications may reduce populations of natural enemies such as big eyed bug, *Geocoris pallens* Stal and *G. punctipes* Say; minute pirate bug, *Orius tristicolor* White; and mites in the family Phytoseiidae that effectively maintain spider mite densities at low levels when not disturbed (Smith and Furr 1975). The neonicotinoids have also been shown to have a hormoligant effect on spider mites (Sclar et al. 1998). Regardless of the specific reason for the recent increase in spider populations on cotton seedlings, research is needed to quantify the relationship between thrips management practices and twospotted spider mite densities. The objective of the current experiment was to determine the impact of at-planting insecticides alone and in combination with foliar applications of acephate on twospotted spider mite densities and injury in cotton.

Materials and Methods

These studies were conducted at the R. R. Foil Plant Science Research Center located in Starkville, MS during 2010 and at the Delta Research and Extension Center in Stoneville, MS during 2011. Phytogen 375 WRF cotton variety was used at both locations.

During 2010, plots were planted on May 7, 2010, infested on May 24, 2011, and rated on May 28, June 4, and June 11, 2010. During 2011 at Starkville, MS, poor environmental conditions prevented an adequate crop stand in three planting attempts. The experiment was planted at Stoneville, MS on June 30, 2011; infested on July 13, 2011; and rated on July 20, 27, and August 3, 2011. Plant populations ranged between 98,800 to 111,150 plants per hectare and for both years.

Treatments were in a factorial arrangement in a randomized complete block design with four replications. The main effects included three levels of at-planting insecticides, three levels of foliar insecticide, and two levels of twospotted spider mite infestation. The at-planting insecticides included aldicarb at 3.92 kg product / ha; a commercial formulation of imidicloprid plus thiodicarb, applied to the seed at a rate equivalent to 0.375 mg/ai imidacloprid per seed, and a un-treated control. The foliar insecticide treatments included acephate applied at 0.28 kg ai/ha during the 1-2 leaf stage, acephate applied at 0.28 kg ai/ha during the 3-4 leaf stage, and an un-treated control. The twospotted spider mite levels included infested and un-infested. Plot sizes consisted of four rows, 12.19 meters in length on 0.97 m row centers.

All plots, except the un-infested control, were infested when plants across the test area were at the one leaf stage on average. Only the center two rows of each plot were infested. The source of mites came from a greenhouse colony located on the Mississippi State University campus and reared on Kentucky Wonder bush green beans, *Phaseolus vulgaris* L. Twospotted spider mite populations ranged between 150-300 mites per bean plant per row foot. The infested green beans were clipped near the soil surface and placed directly over the top of cotton plants, ensuring direct contact between cotton foliage and green bean foliage.

Thrips and twospotted spider mite densities were recorded 4-7, 11-14, and 18-21 days after infestation and the 1-2 leaf foliar acephate application; and 0, 2-7, and 9-14 days after the 3-4 leaf foliar acephate application (Table 3.1). Thrips and twospotted spider mite densities were determined using a whole plant washing technique described by Ota (1968), except that a 2-l 10 percent bleach solution was prepared as the washing solution (Ota 1968, Musser and Catchot 2005). Five random plants were removed equally from all four rows of each plot. Samples were placed in a Ziploc® bag for transportation to the laboratory. In the laboratory, all Ziploc® bags were filled with 1-l of a10 percent bleach solution and agitated to dislodge thrips from the plants and allowed to settle for 5 minutes. All plant tissue and bags were rinsed through 20 and 10 mesh screens to remove large particles. The remaining rinsate was filtered through 9 cm diameter medium porosity filter paper using a 950 ml Pyrex filter flask and vacuum pump. The filter paper was removed from the funnel after all rinsate had been filtered and placed in a Petri dish. Numbers of adult thrips, immature thrips, adult spider mites, and immature spider mites were counted using a Leica MZ7.5 stereomicroscope at 20X magnification.

All data were analyzed with a mixed model analysis of variance (PROC MIXED, SAS Institute, Version 9.2). Due to the late planting date in 2011, yield data were not collected in that year. Therefore, yield data were analyzed from the 2010 experiment only. Thrips and twospotted spider mite densities were pooled across both years for analysis. For analysis of thrips and mite densities, data were transformed using the natural log plus 1 to equalize variance. Non-transformed means and standard errors are presented in the tables. At-planting insecticide, infestation, and insecticide application were designated as fixed effects in the model; replication nested within year was designated as a random effect in the model. The analyses for twospotted spider mite densities were analyzed by spider mite infestation level because no mites were observed in the un-infested plots. For all analyses, degrees of freedom were calculated using the Kenwood-Rodgers method. Means were calculated using the LSMEANS statement and separated based on least significant difference ($\alpha = 0.05$).

Results and Discussion

Thrips densities varied among different treatments in this experiment. At the first rating period (Table 3.1), the only factor that had a significant effect on thrips densities was at-planting insecticide (F=16.18, df=2, 125; $P<0.01$) (Table 3.3). All other factors and their interactions were not significant (Table 3.2). For the effect of at-planting insecticide, the aldicarb and imidacloprid plus thiodicarb treatments had significantly lower thrips densities compared to plots with no at-planting insecticide (Figure 3.3). Previous research has shown imidacloprid and aldicarb provide suppression of thrips (Beckham 1970, Mayer et al. 1987). Mayer et al. (1987) showed significantly lower thrips densities in plots treated with aldicarb at 1 lb/ac.

At the second rating period (Table 3.1), at-planting insecticide (F=9.68, df=2, 125; $P<0.01$), foliar spray (F=4.96, df=2, 125; $P<0.01$), and infestation (F=5.35, df=2, 125; $P=0.02$) had a significant effect on thrips densities (Table 3.2). All other factors and their interactions were not significant (Table 3.2). For the effect of at-planting insecticide, the aldicarb and imidacloprid plus thiodicarb treatments had significantly lower thrips densities compared to plots with no at-planting insecticide (Table 3.4). For the effect of foliar spray treatment, the 1-2 leaf acephate application had significantly higher thrips densities compared to the un-treated and 3-4 leaf foliar application (Table 3.4). Previous research has shown foliar application of acephate suppresses thrips populations

(Creighton and McFadden 1974). However, this rating was made 11-14 days after the 1-2 leaf foliar acephate application and no longer provided residual control of the thrips population. For the effect of infestation, the plots artificially infested with two-spotted spider mites had significantly higher thrips densities compared to the non-infested (Table 3.4). Western flower thrips, *Frankliniella occidentalis* (Pergande), are known as omnivorous opportunist, meaning they will feed on plant and animal material (Trichilo and Leigh 1986). Trichilo and Leigh (1986) showed an increase in larval and adult western flower thrips predatory response to increased twospotted spider mite eggs.

At the third rating period (Table 3.1), foliar spray treatment was the only factor that had an impact on thrips densities (F=4.58; df=2, 125; P=0.01). All other factors and interactions were not significant (Table 3.2). For the effect of foliar spray, the un-treated and 3-4 leaf foliar spray had significantly higher thrips densities compared to the 1-2 leaf acephate application (Table 3.5).

Two-spotted spider mite densities remained consistent across treatments in this experiment. At the first and second rating period (Table 3.1), all factors and their interactions were not significant (Table 3.6). At the third rating date, foliar spray was the only factor that had an impact on two-spotted spider mite density (F=5.82; df=2, 62; P=0.005) (Table 3.6). For the effect of foliar spray, the 1-2 leaf foliar spray had significantly lower two-spotted spider mite densities compared to the un-treated and 3-4 leaf acephate application (Table 3.7).

Yield was significantly impacted across treatments in this experiment. There was a significant effect of at-planting insecticide (F=6.67; df=2, 45; P<0.01), twospotted spider mite infestation level (F=6.56; df=2, 45; P=0.01), and a significant interaction between at-planting insecticide and foliar acephate application on cotton yield (F=2.58;

df=4, 45.1; *P*=0.05) (Table 3.8). Foliar applications did not significantly improve yields in the aldicarb or imidacloprid plus thiodicarb treatments. In contrast, yield was significantly improved in the plots with no at-planting insecticide where acephate was applied at the 3-4 leaf stage. Aldicarb provides good suppression of twospotted spider mites and in some cases my increase the earliness of cotton to physiological maturity (Leigh 1963, Leigh et al. 1967, Chang and Knowles 1978, Durant 1989). At-planting insecticides used in this study, imidacloprid plus thiodicarb and aldicarb, both provide good suppression of thrips populations (Lohmeyer et al. 2003, Joost and Riley 2005). Commonly, acephate is used to control populations of thrips in cotton. Sweeden et al. (1994) showed a significant yield increase of cow peas when acephate was applied at or before first bloom. However, applying acephate on cow peas during the seedling stage showed no significant positive yield response (Sweeden et al. 1994). Acephate has a half life of approximately 8 days and is not toxic to spider mites (Bouchard and Lavy 1982, Tanigoshi and Fargerlund 1984). An Additive application of acephate may result in un-intended responses from other pest. Often times, twospotted spider mites will benefit from early season acephate applications that control beneficial insect populations. Appling acephate on seedling cotton may allow populations of twospotted spider mites to increase rapidly and often times result in reductions of yield.

Twospotted spider mite infestation had a significant effect on cotton yield (F=6.56; df=2, 45; *P*=0.01) (Table 3.8). For the effect of infestation, plots that were artificially infested with two-spotted spider mites yielded significantly lower than non-infested plots (Fig. 3.1). Previous research has shown that two-spotted spider mites are capable of causing early (pre-bloom) and mid-season (first squaring) yield loss in cotton (Furr and Pfrimmer 1968, Wilson 1993b).

Acephate is a common organophosphate insecticide used in the mid-South to control thrips on cotton seedlings. It is relatively inexpensive and is commonly co-applied with post emergence herbicides during the seedling stages of cotton development, even when threshold densities of insect pests are not present. In this experiment, acephate provided good control of thrips on cotton that did not have an at-planting insecticide. The 3-4 leaf acephate application was the most beneficial timing in terms of yield where an at-planting insecticide was not used. Imidacloprid plus thiodicarb seed treatment and aldicarb soil applied insecticides provided good thrips control without a supplemental acephate application. These data suggest that applying acephate as a foliar spray at the 3-4 leaf stage of cotton development when it is not needed (low thrips densities) and may increase twospotted spider mite densities in some situations. Commonly, acephate is used on seedling cotton to control thrips populations. Appling acephate on seedling cotton while seed treatments may still be providing control could result in un-intended responses from other early season pest. Acephate is not toxic to twospotted spider mites and can result in flaring existing populations by eliminating benefincal insects. Furthermore, appling foliar insecticides such as acephate in the presence of at-planting insecticides may indirectly affect cotton yields by increasing twospotted spider mite populations. Yield data should be interpreted with caution because they were only obtained from one year of these experiments. In that year, spider mites significantly reduced yields of cotton regardless of the thrips management strategy. These data will be important for developing an integrated pest management strategy that considers the influence of both thrips and twospotted spider mites on cotton development and yield.

Table 3.1 Timings of thrips and twospotted spider mite injury ratings for days after twospotted spider mite infestation and days after each foliar insecticide application in 2010 and 2011.

Rating	Infestation	1-2 leaf	3-4 leaf
1	4-7	4-7	---
2	11-14	11-14	2-7
3	18-21	18-21	9-14

Table 3.2 Test of fixed effects for mean thrips densities at the first, second, and third rating dates as impacted by at-planting insecticides, foliar acephate applications, and twospotted spider mite infestation

	P>F		
Effect	**1[1]**	**2[2]**	**3[3]**
At-Plant*Spray*Infest	0.91	0.52	0.71
At-Plant*Spray	0.35	0.55	0.58
At-Plant*Infest	0.96	0.82	0.17
Spray*Infest	0.87	0.28	0.54
At-Plant	<0.01	<0.01	0.56
Spray	0.69	<0.01	0.01
Infest	0.09	0.02	0.71

[1] 4-7 days after the 1-2 leaf foliar acephate application.
[2] 11-14 days after the 1-2 leaf foliar acephate application and 2-7 days after the 3-4 leaf foliar acephate application.
[3] 18-21 days after the 1-2 leaf foliar acephate application and 9-14 days after the 3-4 leaf foliar acephate application

Table 3.3 Mean (SE) thrips densities averaged across both years 4-7 days after twospotted spider mite infestation and 1-2 leaf acephate application. Means followed by a common letter are not significantly different (α=0.05).

At-Planting Treatments	**Mean**
Un-Treated	6.25 ± 0.86 b
Aldicarb	3.33 ± 0.59 b
Imidacloprid + Thiodicarb	83.33 ± 14.18 a

Table 3.4 Mean (SE) thrips densities averaged across both years 11-14 days after twospotted spider mite infestation and 1-2 leaf acephate application, and 2-7 days after the 3-4 leaf acephate application. Means followed by a common letter are not significantly different (α=0.05).

At-Planting Treatments	**Mean**
Un-Treated	7.00 ± 1.26 b
Aldicarb	4.29 ± 0.99 b
Imidacloprid + Thiodicarb	28.84 ± 5.26 a
Foliar Spray	
Un-Treated	6.00 ± 1.21 a
1-2 L	11.21 ± 3.07 a
3-4 L	22.92 ± 5.36 b
Infestation	
Infested	16.64 ± 3.46 a
Non-Infested	10.11 ± 2.75 b

Table 3.5 Mean (SE) thrips densities averaged across both years 18-21 days after twospotted spider mite infestation and 1-2 leaf acephate application, and 9-14 days after the 3-4 leaf acephate application. Means followed by a common letter are not significantly different (α=0.05).

Foliar Application	**Mean**
Un-Treated	8.00 ± 0.99 a
1-2 L	6.17 ± 0.89 b
3-4 L	12.00 ± 1.55 a

Table 3.6 Test of fixed effects for mean twospotted spider mite densities at the first, second, and third ratings as impacted by at-planting insecticides and foliar acephate application

		P>F	
Effect	**1[1]**	**2[2]**	**3[3]**
At-plant*Spray	0.84	0.77	0.16
At-plant	0.19	0.53	0.08
Spray	0.47	0.92	<0.01

[1] 4-7 days after the 1-2 leaf foliar acephate application.
[2] 11-14 days after the 1-2 leaf foliar acephate application and 2-7 days after the 3-4 leaf foliar acephate application.
[3] 18-21 days after the 1-2 leaf foliar acephate application and 9-14 days after the 3-4 leaf foliar acephate application.

Table 3.7 Mean (SE) twospotted spider mite densities averaged across both years 18-21 days after twospotted spider mite infestation and 1-2 leaf acephate application, and 9-14 days after the 3-4 leaf acephate application. Means followed by a common letter are not significantly different (α=0.05).

Foliar Application	**Mean**
Un-Treated	19.46 ± 5.71 a
1-2 L	40.42 ± 13.94 b
3-4 L	51.50 ± 15.53 b

Table 3.8 Test of fixed effects for mean cotton yields as impacted by at-planting insecticides, foliar acephate applications, and twospotted spider mite infestation.

Yield	**P>F**
At-plant*Spray*Infest	0.41
At-plant*Spray	0.05
At-plant*Infest	0.79
Spray*Infest	0.21
At-plant	<0.01
Spray	0.15
Infest	0.01

Table 3.9 Mean ± (SE) yields for the at-planting insecticide by foliar spray interaction. Means followed by a common letter are not significantly different (α=0.05).

	At-Planting Insecticide		
Foliar Spray	Un-Treated	Aldicarb	Aeris
Un-Treated	1026.9 ± 125.4 c	1412.5 ± 88.3 ab	1325.5 ± 115.3 ab
1-2 L	918.8 ± 87.2 c	1163.7 ± 72.8 abc	1298.4 ± 99.8 ab
3-4 L	1340.0 ± 98.3 ab	1099.3 ± 86.7 bc	1427.0 ± 128.4 a

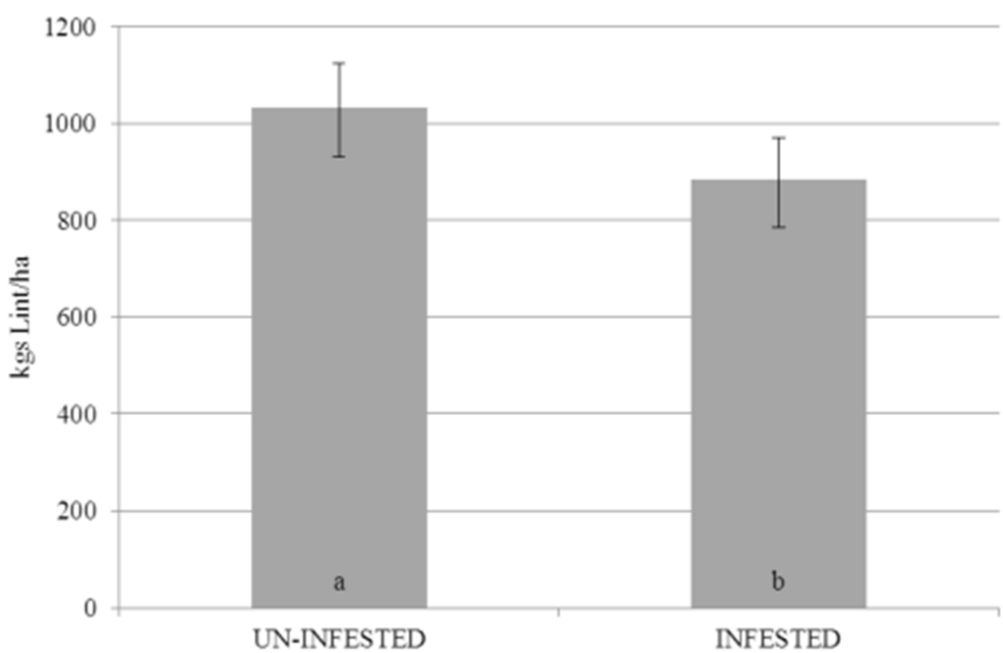

Figure 3.1 Impact of twospotted spider mite infestations on mean (SE) cotton yields during 2010. Means followed by a common letter are not significantly different (α=0.05).

CHAPTER IV

TEMPORAL AND SPATIAL DISTRIBUTION OF TWOSPOTTED SPIDER MITE IN COTTON

Abstract

Experiments were conducted to quantify the temporal and spatial distribution of twospotted spider mite, *Tetranychus urticae* Koch, in cotton. Twospotted spider mites from a greenhouse colony were released at a central location in large blocks of cotton during 2010 and 2011. The blocks were replicated four times in each year. Spider mite densities and injury were measured at specified distances from the point of infestation on three dates. Significant differences in twospotted spider mite injury were found between distances from the point of infestation at the three rating dates in both years. Additionally, significant differences in mite injury ratings were found between rating dates at the four distances away from the initial infestation point. In general, as distance from the point of infestation increased, twospotted spider mite injury decreased and as time after infestation increased, spider mite injury increased. In 2010, twospotted spider mite injury was first detected at the farthest distance 7 m from the initial infestation point 16 and 29 days after infestation in 2010 and 2011, respectively. At 6 and 7 m from the point of infestation, spider mite injury ratings averaged less than 1.0 at 29 days after infestation. After an additional 9 days, spider mite injury ratings increased to 1.6 at 6 m and 1.4 at 7 m. Distance away from the initial point of infestation had a significant effect on cotton yields when averaged across locations and years. Yields were significantly lower on rows

nearest the point of infestation compared to rows more distant from the point of infestation. These data suggest that spider mites and their subsequent injury can spread fairly rapidly under hot and dry conditions, experienced in these trials.

Introduction

The twospotted spider mite, *Tetranychus urticae* Koch, historically has been considered a late season pest of cotton, *Gossypium hirsutum* L., in the midsouthern United States. Early season spider mite infestations have become more prevalent in cotton fields since 2005 (A.L. Catchot, personal communication) and it was the third most damaging arthropod pest of cotton in that year (Williams 2006). Cotton losses due to spider mites are strongly influenced by environmental conditions and the growth stage when infestations occur (Reddall et al. 2004). Significant reductions in cotton yield, fiber quality, and seed viability are all related to when twospotted spider mite time of infestation occurs and the rate of population development (Wilson 1993a). Furr and Pfimmer (1968) showed a significant decrease in cotton yield when plants were infested early-season and mid-season, but yield reductions were not observed for late season infested cotton.

Environmental conditions directly affect spider mite population dynamics. Temperatures greater than 33°C increase reproductive rates and decrease generation times (Klubertanz et al. 1991). At 27°C, twospotted spider mites are able to develop from egg to adults in 5.6 days (Shih et al. 1976). Dry environmental conditions promote spider mite metabolic rates by increasing their demand for nutritional fluids (Boudreaux 1958). Rainfall can decrease spider mite populations by increasing the incidence of pathogens and reducing the ambient temperatures which decreases spider mite fecundity

(Klubertanz et al. 1990). Jeppson et al. (1985) found that spider mites take shelter within webbing on the abaxial surface of leaves to avoid rainfall. Research has shown that spider mite populations are greatest in seasons of drought and high ambient temperatures (Shih et al. 1976).

Twospotted spider mites are referred to as colony forming mites. Colony forming mites tend to move less and aggregate more with increased rates of reproduction (Slone and Croft 1998). Crawling and wind assisted "ballooning" serve as the two main mechanism of spider mite dispersal (Wilson et al. 1983). Crawling is the primary dispersal mechanism for twospotted spider mites early in the season when they move from border vegetation into neighboring crop fields (Brandenburg and Kennedy 1982a). Wind serves as their dispersal mechanism during the latter part of the season when formerly suitable hosts such as corn begin to senesce (Wilson et al. 1983). Multiple factors such as fecundity, development time, territoriality, mate searching, and response to plant quality contribute to twospotted spider mite dispersal (Slone and Croft 1998). Spider mites are negatively geotactic, meaning they continue to move upward toward the terminal as the plant grows (Hussey and Parr 1963). This behavior contributes to their ability to aggregate and disperse by wind or phoresy (Slone and Croft 1998). Wilson et al. (1983) found this aggregated pattern to change into a random dispersal as competition and crowding increased.

Although some research has been conducted on twospotted spider mite dispersal during the latter part of the growing season in cotton and on other crops, little information exists about their movement and subsequent injury on cotton seedlings. Because spider mites are becoming more common in cotton seedlings and their ability to cause significant yield losses at that time of the season, research needs to be conducted to quantify twospotted spider mite dispersal rates in cotton seedlings. The current experiment addressed some of these questions.

Materials and Methods

Experiments were conducted at the R. R. Foil Plant Science Research Center located in Starkville, MS and at the Delta Research and Extension Center in Stoneville, MS during 2010 and 2011, respectively, to evaluate the temporal and spatial distribution of twospotted spider mite injury on cotton. Phytogen 375 WRF was the cotton variety used at each location.

During 2010 at Starkville, MS, the experiment was planted on May 7, 2010, infested on May 24, 2010, and rated on June 9, 17, and 23, 2010. In Stoneville, MS during 2011, the experiment was planted on May 16, 2011, infested on June 7, 2011, and rated on July 6, 15, and 20, 2011. Plant populations ranged from 98,800 to 111,150 plants per hectare both years.

There were four replications of the plot at each location. Plots consisted of 16 rows that were 16.32 m in length. Each plot was linearly flagged down each row every 1.02 X 1.02 m blocks. There were 16 total blocks down each row and 16 blocks across each plot creating 256 blocks within each plot. This type of subplot grid arrangement allowed for systematic sampling of mites as they dispersed across neighboring grids from the initial infestation point. Each plot was assigned five categories based upon distance away from initial infestation point for final analysis. Categories consisted of 0, 2, 4, 6, and 7 meters away from infestation point (Figure 4.1).

All plots were artificially infested using a twospotted spider mite colony reared in the greenhouse at Mississippi State University. Twospotted spider mites were reared on

“Kentucky Wonder”, *Phaseolus vulgaris* L, bush green beans. The green beans were grown in 96 cell flats. Twospotted spider mite population densities ranged between 150-300 mites per bush bean plant. Flats artificially infested with twospotted spider mites were placed in the furrow between rows 8 and 9 and grids 8 and 9 and not directly on the cotton plants to allow natural dispersal onto cotton plants as the green beans senesced.

Twospotted spider mite injury was rated 16, 24 and 30 days after infestation in 2010, and 28, 38, and 48 days after infestation in 2011. Degree of twospotted spider mite injury was determined using a 0-5 scale of reddening and stippling of leaves where; 0 = no damage, 1 = light stippling occurring on leaves within a grid, 2 = stippling and reddening occurring on 15-20% of leaves within a grid, 3 = 20-50% of leaves having a definite reddening on basal portions of leaves within a grid, 4 = greater than 50% of leaves contain extensive reddening within a grid, 5 = greater than 75% of leaves show extensive reddening within a grid (Smith 2010). Injury ratings reflect twospotted spider mite injury that appeared after a whole plant inspection of all plants within each grid.

At the end of the season, the center two rows of each plot were harvested with a spindle-type cotton picker. Additionally, the outermost two rows on each side of the plot (rows 1 and 2, and rows 15 and 16) were harvested. Yields were converted to kg/ha to compare yield loss at the minimum and maximum distance from the point of infestation.

Due to variation in injury rating dates determined by days after infestation each year was analyzed separately from each other. Mean twospotted spider mite injury ratings averaged across all grids within each category were analyzed with a mixed model of analysis of variance (SAS Institute, Version 9.2) For all analyses, degrees of freedom were calculated using the Kenwood-Rodgers method. Means were calculated using the LSMEANS statement and separated based on least significant difference ($\alpha = 0.05$).

Results and Discussion

Starkville, MS 2010

A significant interaction between meters away from point of infestation and days after infestation was observed for the 2010 injury rating data ($F=5.9$; $df=8, 42$; $P<0.01$) (Table 4.1). Additionally, meters away from point of infestation ($F=214.83$; $df=4, 42$; $P<0.01$) and days after infestation ($F=74.95$; $df=2, 42$; $P<0.01$) were significant (Table 4.1). Injury ratings at 16 and 24 days after infestation were no significantly different from each other at 0, 2, 4, and 6 meters away from the point of infestation, but they were significantly different than the rating at 30 days after infestation at each of these distances. In contrast, no differences were observed among the rating intervals at 7 meters from the point of infestation. On June 10, 2010 a rainfall event of 1.47 cm was sustained 1 day after the 16 days after infestation injury rating and likely affected twospotted spider mite populations and injury ratings between the 16 and 24 days after infestation. Population densities were not documented within grids but it is likely that plant vigor and growth was more rapid than twospotted spider mite population increases. Rainfall can directly inhibit twospotted spider mite injury throughout the growing season and could negatively affect their feeding habits, mobility, and population survivorship even at low levels of precipitation (Klubertanz et al. 1990).

At 16 and 24 days after infestation, twospotted spider mite injury ratings were significantly higher at the point of infestation (Table 4.1). Additionally, ratings at 2 meters from the point of infestation were significantly different than those ratings 4, 6, and 7 meters from the point of infestation at those rating dates. At 30 days after infestation, all distances from the point of infestation were significantly different from each other with the exception of 6 and 7 meters away from the initial point of infestation

(Table 4.2). Twospotted spider mites are presumed to inhabited grids 7 m away from initial point of infestation prior to the 16 day injury rating without visible injury present. Spider mite injury within this trial traveled at a rate of 0.44 m per day to reach 7 m away from initial point of infestation within at least 16 days after infestation.

Symptoms of spider mite injury decreased in the 4, 6, and 7 meter distances 24 days after infestation and increased to higher levels by 30 days after infestation. The reason for this decrease is not fully understood, but may have been related to the rainfall event that occurred on June 10, 2011 that totaled 1.47 cm. There are two possible reasons that rainfall may have impacted our results. The added moisture may have triggered a pathogenic fungus such as *Neozygites floridana* Weiser & Muma, (Brandenburg and Kennedy 1982b). Also, sufficient soil moisture may have increased seedling vigor and made detection of low levels of injury more difficult.

Stoneville, MS 2011

No significant interaction between meters away from point of infestation and days after infestation was observed for the 2011 injury rating data (F=1.00; df=8, 42; P=0.50) (Table 4.2). However, the main effects, meters away from point of infestation (F=50.03; df=4, 42; P<0.01) and days after infestation (F=73.39; df=2,42; P<0.01) were significant (Table 4.2).

All distances were significantly different from each other with the exception of 6 and 7 meters from the initial point of infestation, when averaged across all rating dates (Table 4.2). Significant differences were observed in twospotted spider mite injury ratings for the different rating dates when averaged across distances from the point of infestation (Table 4.2). As days after infestation increased, twospotted spider mite injury ratings increased. The mean injury ratings were significantly higher at 38 days after infestation when compared to 29 days after infestation (Table 4.2). The mean injury ratings were significantly higher at 43 days after infestation when compared to 29 and 38 days after infestation (Table 4.2). Spider mite injury increased at later rating intervals for all of the distances from the point of infestation.

In 2011, symptoms of spider mite injury were detected at the farthest distances from the point of infestation, 7 m, within 29 days after infestation. At 29 days after infestation twospotted spider mite injury averaged less than 1; 6 and 7 meters away from initial point of infestation. Within an additional 9 days, spider mite injury increased to 1.6 at 6 m and 1.4 at 7 m. Environmental conditions remained hot and dry at Stoneville, MS during 2011. These types of conditions inhibit twospotted spider mite fecundity, dispersal and overall survivorship (Brandenburg and Kennedy 1982a, Wilson et al. 1983, Klubertanz et al. 1990). As twospotted spider mites feed on cotton plants, less available nutrients are present. This lack of nutrients along with high populations of spider mites on cotton leaves triggers a dispersal mechanism (Hussey and Parr 1963). Plotting distance as a function of degree of injury resulted in a linear effect as days after infestation increased injury ratings increased.

Yield Data, Starkville, MS 2010 and Stoneville, MS 2011

Distance away from initial point of infestation had a significant effect on cotton yields when averaged across locations and years ($F=6.87$, $df=2, 14$, $P<0.008$) (Figure 4.2). Yields were significantly lower on rows nearest the point of infestation compared to rows more distant from the point of infestation. There was an approximately 16 to 29 day delay in the establishment of twospotted spider mites on the outer rows compared to the point of infestation. Therefore, injury was established earlier, reached higher levels, and persisted longer at the point of infestation compared to the outer rows. These factors are the most likely reasons for the difference in yield.

These data suggest that spider mites and their subsequent injury can spread fairly rapidly under certain environmental conditions. Environmental conditions were generally hot and dry at the time of these experiments. These results may be significantly different with cooler temperatures or significant rainfall. Adequately describing twospotted spider mite temporal and spatial dispersal was achieved. However, this trial and future trials would benefit if twospotted spider mite population densities within grids was known. More so, an un-infested control would be beneficial in understanding precise reductions in yields.

Table 4.1 Mean (SE) twospotted spider mite injury 16, 24, and 30 days after twospotted spider mite infestation during 2010. Means followed by a common letter are not significantly different (α=0.05).

	Days After Infestation			
Distance (m)	16	24	30	Mean
0	2.62 ± 0.36 b	2.25 ± 0.31 b	4.00 ± 0.32 a	2.96
2	1.05 ± 0.16 c	0.96 ± 0.23 c	2.47 ± 0.19 b	1.50
4	0.32 ± 0.06 de	0.15 ± 0.06 de	1.12 ± 0.16 c	0.54
6	0.11 ± 0.04 e	0.01 ± 0.01 e	0.53 ± 0.15 d	0.22
7	0.07 ± 0.02 e	0.00 ± 0.00 e	0.29 ± 0.12 de	0.12
Mean	0.84	0.68	1.69	

Table 4.2 Mean (SE) twospotted spider mite injury 29, 38, and 43 days after twospotted spider mite infestation during 2011. Means within a row followed by a common uppercase letter and within a column followed by a common lowercase letter are not significantly different (α=0.05).

	Days After Infestation			
Distance (m)	29	38	43	Mean
0	3.25 ± 0.14	3.75 ± 0.51	4.38 ± 0.30	3.79 a
2	1.90 ± 0.24	2.94 ± 0.69	3.77 ± 0.21	2.87 b
4	0.68 ± 0.23	2.14 ± 0.68	2.97 ± 0.14	1.93 c
6	0.31 ± 0.17	1.64 ± 0.56	2.56 ± 0.15	1.50 d
7	0.21 ± 0.14	1.48 ± 0.51	2.32 ± 0.14	1.33 d
Mean	1.27 C	2.39 B	3.20 A	

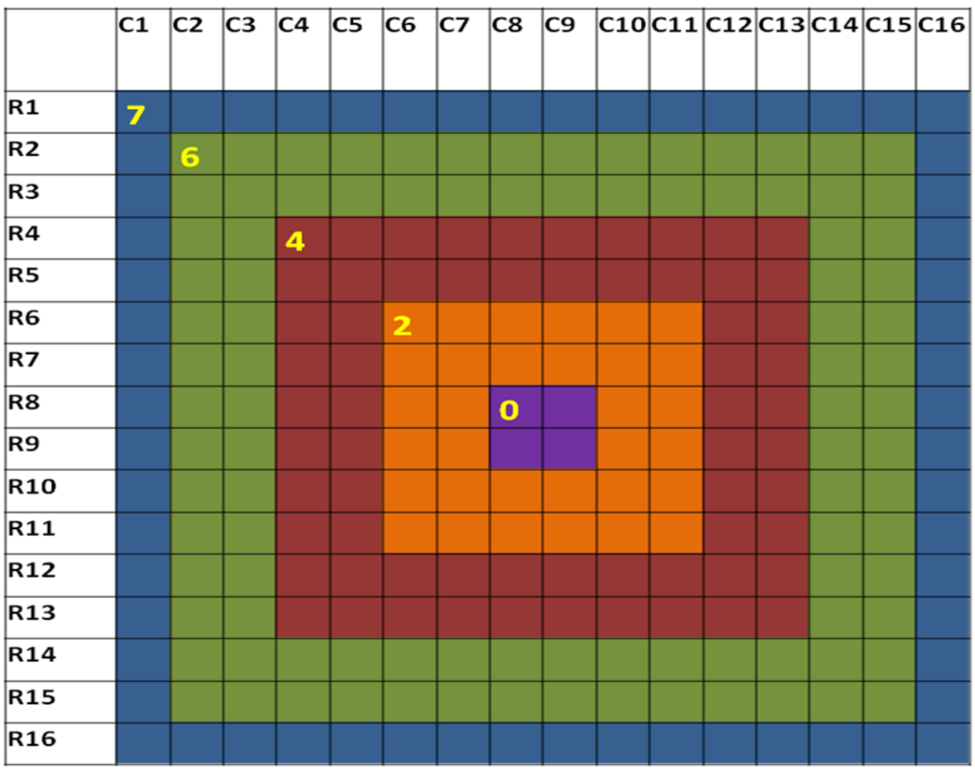

Figure 4.1 Plot layout for categories based on distance in meters from the point of infestation (0=point of infestation).

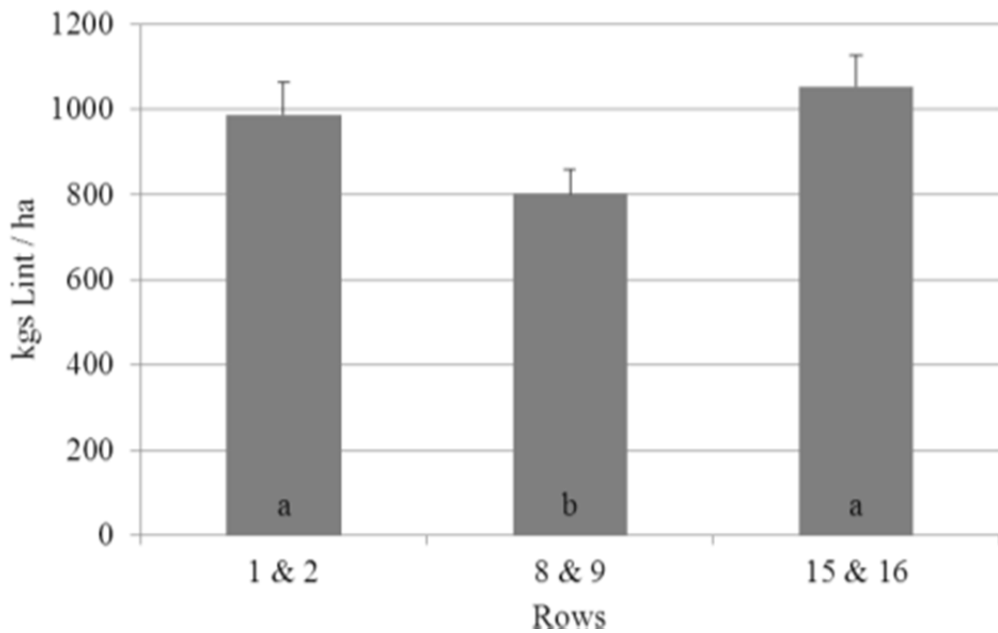

Figure 4.2 Impact of twospotted spider mite infestations on mean (SE) cotton yields averaged across both years. Means followed by a common letter are not significantly different (α=0.05).

REFERENCES

Beckham, C. M. 1970. Influence of systemic insecticides on thrips control and yield of cotton. Journal of Economic Entomology 63: 936-938.

Bouchard, O. C., and T. L. Lavy. 1982. Fate of Acephate in the Cotton Plant. Journal of Economic Entomology 75: 921-923.

Boudreaux, B. 1963. Biological aspects of some phytophagous mites. Annual Review of Entomology 8: 137-154.

Boudreaux, H. B. 1958. The effect of relative humidity on egg-laying, hatching, and survival in various spider mites. Journal of Insect Physiology 2: 65-72.

Brandenburg, R., and G. Kennedy. 1982a. Intercrop relationships and spider mite dispersal in a corn/peanut agro-ecosystem. Entomologia Experimentalis et Applicata 32: 269-276.

Brandenburg, R. L., and G. G. Kennedy. 1982b. Relationship of *Neozygites floridana* (Entomophthorales: Entomophthoraceae) to two-spotted spider Mite (Acari: Tetranychidae) populations in field corn. Journal of Economic Entomology 75: 691-694.

Burris, E., A. M. Pavloff, B. R. Leonard, J. B. Graves, and G. Church. 1990. Evaluation of two procedures for monitoring populations of early season insect pests (Thysanoptera: Thripidae and Homoptera: Aphididae) in cotton under selected management strategies. Journal of Economic Entomology 83: 1064-1068.

Cagle, L. R. 1949. Life history of the twospotted spider mite. VA Agri. Exp. Stn. Tech. Bull. 113: 1-31.

Carbide, U. 1975. Temik aldicarb pesticide: A scientific assessment. *In* U. C. A. P. Company [ed.], Research Triangle Park, NC.

Catchot, A. 2011. 2012 Insect control guide for agronomic crops, vol. 2471, Mississippi State University, Mississippi State University.

Chang, K.-M., and C. O. Knowles. 1978. Aldicarb metabolism in two-spotted spider mites. Journal of Economic Entomology 71: 158-160.

Cook, D., A. Herbert, D. S. Akin, and J. Reed. 2011. Biology, crop injury, and management of thrips (Thysanoptera: Thripidae) infesting cotton seedlings in the United States. Journal of Integrated Pest Management 2: B1-B9.

Cook, D. R., C. T. Allen, E. Burris, B. L. Freeman, and F. A. Herzog. 2003. A survey of thrips (Thysanoptera) species infesting cotton seedlings in Alabama, Arkansas, Georgia, Louisiana, Mississippi, and Tennessee Journal of Entomological Science 38: 669-681.

Cook, D. R., B. R. Leonard, M. M. Willrich, J. Gore, and R. H. Gable. 2004. Residual toxicity of seed treatments and soil applied insecticides to tarnished plant bug, Lygus lineolaris (Palisot Beauvois), in Cotton. J. Agri. Urban Entomol. 20: 187-192.

Creighton, C. S., and T. L. McFadden. 1974. Chemical Control of Aphids and Thrips on Southern Pea Seedlings. Journal of Economic Entomology 67: 693-694.

Durant, J. A. 1989. Yield Response of Cotton Cultivars to Early-Season Applications of Chlordimeform and Aldicarh. Journal of Economic Entomology 82: 626-632.

Foley, W. J., A. Acllwee, I. Lawler, L. Aragones, A. P. Woolnough, and N. Berding. 1998. Ecological application of near infrared reflectance spectroscopy a tool for rapid, cost-effective prediction of the composition of plant and animal tissues and aspects of animal performance. Oecologia 116: 293-305.

Furr, R. E., and T. R. Pfrimmer. 1968. Effects of early-, mid-, and late-season infestations of two-spotted spider mites on the yield of cotton. Journal of Economic Entomology 61: 1446-1447.

Furr, R. E., and L. B. Davis. 1969. Acaricides for control of the two-spotted spider mite on cotton In the field. Journal of Economic Entomology 62: 732-733.

Hagel, G. T. 1970. Systematic insecticides and control of insects and mites on beans. Journal of Economic Entomology 63: 1487-1489.

Hazan, A., A. S. Tahori, and U. Greson. 1974. Spider mite webbing. The production of webbing under various enviromental conditions. Acarologia 16: 68-84.

Hussey, N. W., and W. J. Parr. 1963. Dispersal of the glasshouse red spider mite *Tetranychus urticae* Koch (Acarina, Tetranchidae). Entomologia Experimentalis et Applicata 6: 207-214.

Jeppson, L. R., H. H. Keifer, and E. W. Baker. 1975. Injurious tetranychid mites, pp. 234-236, Mites Injurious to Economic Plants. University of California Press.

Joost, P. H., and D. G. Riley. 2005. Imidacloprid Effects on Probing and Settling Behavior of Frankliniella fusca and Frankliniella occidentalis (Thysanoptera: Thripidae) in Tomato. Journal of Economic Entomology 98: 1622-1629.

Kavousi, A., H. Chi, K. Talebi, A. Bandani, A. Ashouri, and V. H. Naveh. 2009. Demographic traits of *Tetranychus urticae* (Acari: Tetranychidae) on leaf discs and whole leaves. Journal of Economic Entomology 102: 595-601.

Klubertanz, T. H., L. P. Pedigo, and R. E. Carlson. 1990. Effects of plant moisture stress and rainfall on population dynamics of the two-spotted spider mite (Acari: Tetranychidae). Environmental Entomology 19: 1773-1779.

Klubertanz, T. H., L. P. Pedigo, and R. E. Carlson. 1991. Impact of fungal epizootics on the biology and management of the two-spotted spider mite (Acari: Tetranychidae) in soybean. Environmental Entomology 20: 731-735.

Leigh, T. F. 1963. Control of certain insects and mites on cotton with three systemic organophosphorous compounds. Journal of Economic Entomology 56: 327-333.

Leigh, T. F., C. E. Jackson, V. E. Burtom, and H. J. Eblack. 1967. Acaracides for tetranychid mite control of cotton. Journal of Economic Entomology 60: 718-723.

Lohmeyer, K. H., J. N. All, P. M. Roberts, and P. Bush. 2003. Precision application of aldicarb to enhance efficiency of thrips (Thysanoptera: Thripidae) management in cotton. Journal of Economic Entomology 96: 748-754.

Mahey, R. K., R. Singh, S. S. Sidhu, and R. S. Narang. 1991. The use of remote sensing to assess the effects of water stress on wheat. Experimental Agriculture 27: 429-429.

Mayer, D. F., J. D. Lunden, and L. Rathbone. 1987. Evaluation of Insecticides for Thrips tabaci (Thysanoptera: Thripidae) and Effects of Thrips on Bulb Onions. Journal of Economic Entomology 80: 930-932.

Musser, F. R., and A. L. Catchot. 2005. Roundup-insecticide synergy evaluation on thrips. Arthopod Management Test: F32.

Oatman, E. R. 1970. Integration of phytoseiulus persimilis with native predators for control of the two-spotted spider mite on Rhubarb. Journal of Economic Entomology 63: 1177-1180.

Ota, A. K. 1968. Comparison of three methods of extracting the flower thrips from rose flowers. Journal of Economic Entomology 61: 1754-1755.

Pierce, F. J., and P. Nowak. 1999. Aspects of precision agriculture. Advances in Agronomy 67: 1-85.

Potter, D. A., D. L. Wrensch, and D. E. Johnston. 1976. Guarding, aggressive behavior, and mating success in male twospotted spider mites. Annals of the Entomological Society of America 69: 707-711.

Reddall, A., V. O. Sadras, L. J. Wilson, and P. C. Gregg. 2004. Physiological responses of cotton to two-spotted spider mite damage. Crop Science 44: 835-846.

Reisig, D., and L. Godfrey. 2006. Remote sensing for detection of cotton aphid (Homoptera: Aphididae) and spider mite (Acari: Tetranychidae) infested cotton in the San Joaquin valley. Environmental Entomology 35: 1635-1646.

Ridgway, R. L., L. J. Gorzycki, and D. A. Lindquist. 1965. Evaluation of systemic insecticides for cotton insect control. Journal of Economic Entomology 58: 666-669 (664).

Riley, J. R. 1989. Remote sensing in entomology. Annual Review of Entomology 34: 247-271.

Sclar, D. C., D. Gerace, and W. S. Cranshaw. 1998. Observations of population increases and injury by spider mites (Acari: Tetranychidae) on ornamental plants treated with imidacloprid. Journal of Economic Entomology 91: 250-255.

Shih, C. I. T., S. L. Poe, and H. L. Cromroy. 1976. Biology, life table, and intrinsic rate of increase of *Tetranychus urticae*. Annals of the Entomological Society of America 69: 362-364.

Slone, D. H., and B. A. Croft. 1998. Spatial aggregation of apple mites (Acari: Phytoseiidae, Stigmaeidae, Tetranychidae) as measured by a binomial model: Effects of life stage, reproduction, competition, and predation. Environmental Entomology 27: 918-925.

Smith, J. F. 2010. Early-season management of twospotted spider mite on cotton an dimpacts of infestation timing on cotton yield loss. Doctor of Philosophy in Entomology, Mississippi State Univeristy

Smith, J. W., and R. E. Furr. 1975. Spider mites and some natural control agents found on cotton in the delta area of Mississippi. Environmental Entomology 4: 559-560.

Sweeden, M. B., P. J. McLeod, and W. R. Russell. 1994. Acephate effect on dryland and irrigated cowpeas when applied for thrips (Thysanoptera: Thripidae) and com earworm (Lepidoptera: Noctuidae) control. Journal of Economic Entomology 87: 1627-1631.

Tanigoshi, L. K., and J. Fargerlund. 1984. Implications of Parathion Resistance and Toxicity of Citricultural Pesticides to a Strain of Euseius hibisci (Chant) (Acarina: Phytoseiidae) from the San Joaquin Valley of California. Journal of Economic Entomology 77: 789-793.

Trichilo, P. J., and T. F. Leigh. 1986. Predation on Spider Mite Eggs by the Western Flower Thrips, Frankliniella occidentalis (Thysanoptera: Thripidae), an Opportunist in a Cotton Agroecosystem. Environmental Entomology 15: 821-825.

Williams, M. R. 2006. Cotton insect losses, pp. 1151-1204, Proceedings of the 2005 Beltwide Cotton Conference. National Cotton Council, Memphis, TN, San Antonio, TX

Williams, M. R. 2010. Cotton insect losses 2009, pp. 897-940, Proceedings of the 2008 Beltwide Cotton Conference. National Cotton Council, Memphis TN, San Antonio, TX.

Williams, M. R. 2011. Cotton insect losses-2010 Proceedings of the 2010 Beltwide Cotton Conference. National Cotton Council, Memphis, TN, Atlanta, GA.

Wilson, L. J. 1993a. Spider Mites (Acari: Tetranychidae) Affect Yield and Fiber J. Econ. Entomol. 86: 566-585.

Wilson, L. J. 1993b. Spider mites (Acari: Tetranychidae) affect yield and fiber quality of cotton. Journal of Economic Entomology 86: 566-585.

Wilson, L. T., D. Gonzalez, T. F. Leigh, V. Maggi, C. Foristiere, and P. Goodell. 1983. Within-plant distribution of spider mites (Acari: Tetranychidae) on cotton: a developing implementable monitoring program. Environmental Entomology 12: 128-134(127).

Zhang, N., M. Wang, and N. Wang. 2002. Precision agriculture a worldwide overview. Computers and Electronics in Agriculture 36: 113-132.